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The Future of Agriculture: Science Stewardship and Sustainability

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PREFACE AND ACKNOWLEDGEMENT

PREFACE

About the Conference

The U.S. Environmental Protection Agency (EPA), the National Institute of Environmental Health Sciences (NIEHS), and the Center for Hazardous Substance Research (CHSR) at Kansas State University, a consortium member of the Midwest Hazardous Substance Research Center (HSRC), hosted the *International Conference on The Future of Agriculture: Science, Stewardship, and Sustainability (Integrating Science, Technology, and Policy to Address Environmental Challenges in the Agricultural Setting)* on August 7-9, 2006 at theHyatt Regency in downtown Sacramento, California.

The west coast of North America and the Pacific Rim area present a unique blend of challenges and innovative solutions at the confluence of agriculture and environment. Many stakeholders, with diverse perspectives presented orginal reseach results and participated in a dialogue on new opportunities and recent successes for practical problem-solving.

Kansas State University organized this conference as part of its Environmental Protection Agency (EPA) Hazardous Substance Research Center (HSRC) outreach and technology transfer mission, in partnership with US EPA ORD Hazardous Substance Technical Liaisons Program, the California Department of Food and Agriculture (CDFA), California EPA, and the United States Department of Agriculture Agricultural Research Service (USDA-ARS). The conference is also being sponsored by the National Institute of Environmental Health Sciences (NIEHS), whose Superfund Basic Research Program supports research at the University of California, Davis, among other institutions.

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Pest and Nutrient Management

INTERVENTION TO REDUCE TAKE-HOME PESTICIDE EXPOSURE TO FARMWORKERS AND THEIR FAMILIES

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Abstract
The U.S. EPA Worker Protection Standard (WPS) provides basic information to farmworkers about potential pesticide exposure and ways to minimize contact with pesticides. Combined with re-entry intervals after application, these regulations are designed to protect farmworker health. Little research has been conducted on whether WPS concepts are effectively reaching farmworkers and whether additional steps to prevent pesticide exposure may prevent both farmworker exposure and take-home exposure to their families. We conducted a field-based intervention with strawberry workers (n=130) to assess malathion exposure and determine whether education, provision of warm water to increase handwashing, and use of gloves and coveralls that can be removed before entering worker homes reduced the potential for take-home exposure to farmworkers and their families. To assess potential exposure and efficacy of the intervention, we measured malathion in foliage (dislodgeable residues), hand rinses, clothing patch samples, and dimethyl organophosphorous and malathion-specific metabolite in urine. We also used questionnaires, non-participant observation, focus groups, and in-depth interviews to assess both workers' and growers' reactions to the intervention. Preliminary data analysis indicates potential for take-home exposure based on malathion residue in foliage, hand-rinse samples, and clothing samples. Urinary metabolite data indicate that malathion exposures are directly related to use in the fields, and that wearing protective gloves while working could reduce pesticide exposure to farmworkers and their families. We also found that eating unwashed strawberries in the field was an important source of malathion exposure in these workers ($p<0.01$). Implication of this intervention study for worker safety and reducing children's pesticide exposure will be discussed.

Key words: occupational pesticide exposure, farmworkers, malathion, intervention

USE OF IMMUNOASSAYS FOR HUMAN AND ENVIRONMENTAL MONITORING OF AGROCHEMICALS.

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Abstract

To evaluate risks to humans and the environment due to agrochemical exposures, a large number of studies that generate staggering numbers of analyses are necessary. Good analytical methods can be costly and thus limit the extent of such studies. To address this issue, we developed immunochemical methods of analysis and other integrated immunochemical techniques for monitoring toxic substances in humans and the environment. Immunoassays are advantageous because they are sensitive, selective, rapid, cost-effective, and adaptable. They can be used to monitor individual chemicals, metabolites or bound species. Recently conducted biological monitoring studies using immunoassay to measure paraquat or atrazine in occupationally exposed workers will be presented. Large-scale monitoring studies also require higher throughput and often, greater sensitivity. Relevant work from this and other laboratories will be presented. For example, in our laboratory higher throughput approaches, such as adapting a pesticide metabolite assay to an autoanalyzer using chemiluminescent acridinium labels is one approach to increasing throughput. To increase sensitivity, we are developing immunochemical-based biosensors using lanthanide oxide nanoparticles as labels. Use of these nanoparticles in a multiplexed assay and for visualizing protein micropatterns will also be presented. Immunoassay is not a replacement for GC or HPLC, but is an important tool for the analytical chemist and can provide an improved, cost-effective alternative for monitoring.

Key words: immunoassay, monitoring, pesticides

GROWTH-PROMOTING ANTIBIOTICS IN FOOD ANIMAL PRODUCTION: AN ECONOMIC ANALYSIS

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Abstract

Considerable controversy persists regarding use of human antibiotics to promote growth in animals raised for food. Opponents of growth-promoting antibiotics (GPAs) argue that their use leads to increased risks of antibiotic-resistant infections in humans, while supporters argue that their removal will significantly increase production costs and is unlikely to reduce human health risks. The authors examined the economic effect of removing antibiotics used for growth promotion in commercial broiler chickens. In this paper, we utilized data published by the Perdue company, one of the largest poultry producers in the world, in which a non-randomized controlled trial of GPA use was conducted to evaluate the impact of removing GPAs on broiler chicken production. Production changes associated with GPA use were insufficient to offset the cost of the biological agents. The net effect of using GPAs was a lost value of $0.0093 per chicken (about 0.45% of total cost). Based upon these data, we found no basis for the claim that GPAs lower the cost of production. This economic analysis is the first study, to our knowledge, utilizing large-scale empirical data collected by U.S. industry, in which it can be demonstrated that use of GPAs in food animal production is associated with economic losses to producers. These data are of considerable importance in the ongoing national debate concerning the continued registration of antibiotics for growth promotion of food animals. Based on the industry study and the resulting economic impact, use of GPAs in U.S. poultry production should be reconsidered.

Key words: GPAs, poultry production, human health risk

PREDICTORS OF PESTICIDE CONCENTRATIONS IN HOUSE DUST IN AN AREA WITH INTENSE AGRICULTURE

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Abstract
Greater clarification of the sources of pesticides in house dust is needed. In an area with year-round production of high-value fruit and vegetable crops, we collected house dust samples using a high-volume surface sampler, longitude and latitude coordinates (GPS), and questionnaire responses from 241 homes. Dust samples were analyzed for 18 pesticides by gas chromatography /mass spectroscopy. Quantile regression was used to determine associations between dust concentrations and independent variables. Results are as follows: diazinon, chlorpyrifos, chlorthal-dimethyl, and permethrin were most frequently detected (86% or more of samples, detection limits 1-5 ng/g) and were selected for further statistical analysis. Initial univariate regression analysis demonstrated significant ($p<0.01$) associations of pesticide concentrations with independent variables including farmworkers wearing work shoes/clothes in the home, dirt entrance to the home, and living in poverty. Further, reported nearby (within 1.5 miles) agricultural pesticide use on days 1-60 prior to dust collection was significantly associated with chlorthal-dimethyl concentrations. For each pesticide, final multivariate models on the median and 90th percentile of dust concentrations will be presented. In conclusion, our results suggest that nearby agricultural pesticide use and household-specific variables are impacting children's exposure to pesticides.

Key words: pesticides, house dust, diazinon, chlorthal-dimethyl

EVALUATION OF METHYL BROMIDE BUFFER ZONES FOR SOIL APPLICATIONS IN CALIFORNIA

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Abstract
Buffer zones are areas around a treated field where human activities are restricted following application of a pesticide. For methyl bromide recommended buffer zones were established by the California Department of Pesticide Regulation based on computer modeling which used a standard set of meteorological conditions in conjunction with a target 24-hour concentration of 815 ug/m^3. Size of the tabled buffer zones varied from 30 to 3400 feet depending on field size, application rate, and method of application. To test adequacy of the buffer zones for maintaining concentrations below the target level, five years of hourly meteorological data for four stations from the California Irrigation Management Information System (CIMIS) located in high methyl bromide use counties (Fresno, Merced, Ventura, Monterey) were used. The industrial source complex short term (ISCST) model was used to calculate daily maximum-required buffer zones for fields from 1 to 40 acres and fluxes from 30 to 225 pounds/acre-day over 20 years of meteorological data. Daily required buffer zones were compiled into cumulative frequency distributions and the tabled buffer zone values were compared. Tabled buffer zones were protective 89% to 100% of the days.

Key words: methyl bromide, buffer zones, ISCST, CIMIS, soil fumigation

AIRBORNE PESTICIDE DRIFT AND COMMUNITY MONITORING

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Abstract
Airborne pesticides and corresponding inhalation exposures result from spray or dust drift during applications or from volatilization of the chemical after application. We have been working with drift-affected communities to determine the scope and magnitude of inhalation exposures to pesticide drift near sites of high pesticide use. This presentation will discuss results from several California and Washington state locations where soil fumigants and organophosphorus insecticides were found. The particular effect of vapor pressure on drift potential will be discussed. The implications of these results will be discussed in terms of human exposures, as well as potential measures for reducing exposures.

Key words: pesticide drift, community monitoring, agrochemical exposure

INTERIM GUIDANCE FOR SAMPLING AGRICULTURAL FIELDS THAT ARE PROPOSED FOR SCHOOL SITES

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Abstract

Agricultural properties represent a unique class of sites. They tend to be large in acres and have a well-defined group of potential contaminants resulting from the uniform application of agricultural chemicals across the site. Experience has shown that unless the site history indicates otherwise, analysis can be limited to organochlorine pesticides and heavy elemental metals such as arsenic and lead. To establish a uniform approach for evaluating these sites, guidance for sampling and analysis has been developed. Guidelines for determining whether a site or portion of a site is appropriately classified as "agricultural" are also discussed.

Key words: site history, sampling, analysis

PARLIER PILOT – AIR MONITORING FOR PESTICIDES

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Abstract
As part of the California Environmental Protection Agency's Environmental Justice Action Plan, the Department of Pesticide Regulation (DPR) is conducting a pilot project focusing on pesticide air concentrations in Parlier. Parlier is a small agricultural community located in California's San Joaquin Valley. The data gathered will help DPR evaluate exposure to pesticides and identify opportunities to reduce environmental health risk, particularly to children. This project includes additional elements to address cumulative impacts, precautionary approaches, and public participation. DPR, with assistance from other agencies, is monitoring for pesticides as well as other pollutants. Most pesticide monitoring occurs three consecutive days each week at three elementary schools in Parlier. Monitoring began in January 2006 and will continue through December 2006. In the first three months of monitoring, the key findings were as follows.

Of the 37 pesticides or breakdown products for which results were available, 11 of them were detected in one or more of the samples. Diazinon was the pesticide with a concentration closest to its health screening level, 98 nanograms per cubic meter, which is 75 percent of the screening level. DPR detected chlorpyrifos most frequently, in 100 percent of the samples.

Key words: environmental justice, cumulative impacts, precautionary approaches, public participation

MINIMIZING EMISSIONS FROM SOIL FUMIGATION BY SURFACE SEAL METHODS

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Abstract
Soil fumigation is an important management practice for controlling soil pests in many high-value crops. Reducing atmospheric emissions can minimize the impact of soil fumigation on the environment. Water seals (sprinkling water on the soil surface) to reduce fumigant emissions is more cost-effective than plastic tarps. We have conducted a series of soil-column tests and two small-plot field trials to determine the effectiveness pre-irrigation and water seals following fumigation on reducing emissions of 1,3-dichloropropene (1,3-D) and chloropicrin (CP) in comparison with tarps (standard high-density polyethylene, HDPE; or virtually impermeable film, VIF) in a sandy loam soil in the San Joaquin Valley, Calif.. Water application immediately following shank-injection of the fumigants reduced and delayed emission peaks. Intermittent water applications were more effective to reduce emission peaks and total emissions compared to single applications. Irrigation prior to shank-injected fumigation also effectively reduced emissions. Water applications before and after drip-application of fumigants also showed the effectiveness on emission reductions. Results consistently show that water applications to the soil surface can reduce emissions more effectively than HDPE tarp, especially for 1,3-D. An appropriate amount of water and application schedule, however, needs to be determined for different types of soil to ensure adequate fumigation efficacy while reducing emissions.

Key words: soil fumigation, 1,3-dichloropropene, chloropicrin, emission reduction, water seal

Introduction

Soil fumigation is widely used to control soil pests and achieve high yield of many fruit, vegetable, and nursery crops. The phase-out of methyl bromide (MeBr) as a soil fumigant due to its contribution to the depletion of stratospheric ozone has increased the need for alternatives, such as 1,3-dichloropropene (1,3-D), chloropicrin (CP), and metam sodium or potassium (as methyl isothiocyanate[MITC] generator) (CDPR, 2003; Trout, 2005). These alternatives, however, are volatile organic compounds (VOCs) that react with NOx under the sunlight to form harmful ground-level ozone (Segawa, 2005). Use of fumigants is strictly regulated (e.g., township caps and buffer zones) in California and regulations on emissions are likely to become more stringent in the future to protect air quality (CDPR, 2006). It is essential to control fumigant emissions to maintain this management practice for agricultural production while minimizing detrimental impacts on the environment.

Plastic mulch or tarp (the most commonly used is high-density polyethylene [HDPE]) has been used with soil fumigation (e.g., methyl bromide) to control emissions. The HDPE tarp, however, does not effectively control emissions of certain alternative fumigants, particularly 1,3-D (Telone). The cost for using standard HDPE tarp is about \$2000 ha^{-1} in the San Joaquin Valley of California including materials (tarp and glue: \$1240 ha^{-1}), application (\$470 ha^{-1}), and removal and disposal (\$270–\$440 ha^{-1}). Use of films with low permeability (e.g., virtually impermeable film [VIF], metalized film, and semi-impermeable film [SIF]) has been or is being tested in field trials. Although efficacy data with new films appear promising, technical solutions to maintaining their low-permeability properties and consistent performance on emission reductions in large field applications are still being sought. Additionally, the newer plastic films likely will have similar material costs and post-fumigation disposal issues as the current HDPE technologies.

Water seals (water application to the soil surface) should be effective in reducing emissions because diffusion of fumigants in water is much slower than in the air (Yates et al., 2002). Sullivan demonstrated that water seals, especially with intermittent applications, effectively reduced MITC emissions (Sullivan et al., 2004). Little information is available on the effectiveness of water seals on emission reductions of Telone products under field conditions. Major benefits to water seals is substantially reduced costs for materials and post-fumigation disposal. For water seal with a sprinkler system, the cost for a total 25-mm water application is in the range of \$100–700 ha^{-1}, depending on whether growers own or rent the sprinkler system. This estimate is based on an estimated water cost of \$0.04 m^{-3} (\$10 per ha for a 25-mm water application), five worker-h per ha for sprinkler installation and removal (<\$80 per ha), and sprinkler system rental/delivery cost of \$600 per ha (depending greatly on the number of times the system is moved and reused). Using water is also an environmentally friendly practice in comparison to plastic tarps.

For the last two years, we have been focusing our research on water seals to reduce fumigant emissions. We conducted a series of soil-column tests and two small-plot field trials to determine the effectiveness of water seals on emission reductions of 1,3-D and CP from fumigation with Telone products. In this paper, we will report some of the results focusing on emissions and comparisons between water seals and plastic tarps.

Soil-Column Tests

To determine the potential of water seals after fumigation for reducing fumigant emissions, we first conducted a series of soil column tests to compare cis-1,3-D emissions through water seals and plastic tarps (HDPE and VIF). Detailed information about the experiments is reported in Gao and Trout (2006). Hanford sandy loam soil that was collected from the surface was used throughout the study. The soil was packed into stainless steel columns (63.5 cm high x 15.5 cm [i.d.]). One hundred twenty mg of cis-1,3-D was injected to the soil columns at 30-cm depth. Surface treatments included control (dry soil), initial water application (8-mm water sprayed to soil surface just before fumigant application), initial plus a second water application (2.6-mm) at 12 h, initial plus two water applications (2.6-mm each time) at 12 h and 24 h, standard HDPE tarp, initial water application (8-mm) plus HDPE tarp, and VIF tarp. Emissions from the soil surface were measured by collecting the air samples above the soil columns using a flow-through air chamber, which was connected to the top of the soil columns and maintained to a constant air-flow rate of 110 mL min^{-1}. The distribution of 1,3-D in the soil-gas phase of the columns were also sampled and determined. Monitoring was conducted for two weeks after fumigation.

The emission rates (flux) from various column treatments are shown in Fig. 1. The control gave the highest emission rates (up to 16 μg m^{-2} s^{-1}). The initial water application right before fumigant injection reduced and delayed emissions. Each water application after fumigant injection abruptly reduced 1,3-D emission flux, which rebounded over a few hours. Peak emission rates were substantially reduced for water application treatments (Fig. 1 and Table 1). The peak flux of the initial water application only and the intermittent water applications were about 30% and 50%, respectively, of that from the control. The HDPE tarp resulted in similar 1,3-D emission rates as the initial water application only. The VIF tarp reduced the emission rates the most, i.e., resulted in the lowest emission rates (<10% of the control).

Cumulative emission loss was estimated by summing the products of the average of two consecutive emission flux values and the time interval between the two measurements over the time span of the study. Total emission losses over two weeks of measurements are given in Table 1. Water applications to the soil surface reduced total emissions compared to the control, but this difference was less profound than the peak flux reduction (Table 1). Total emission loss was 51% of applied for the control, 46% for initial water application only, and 41% for the treatment with three-time (0, 12, and 24 h) water applications. HDPE tarp alone resulted in 45% emission loss of applied, while initial water application plus HDPE tarp resulted in 38% emission. The most effective soil-surface treatment was VIF tarp (10% emission loss).

Results from the column tests indicated that water applications to the soil surface can be more effective than standard HDPE tarp for reducing 1,3-D emissions. High frequency of water application may be required to substantially reduce total emissions. Fumigant concentrations in the soil-gas phase (data not shown) were not reduced by application of the amount of water used.

Field Trial in Summer 2005

To determine if water seal effectively reduces fumigant emissions under field conditions, we conducted a field trial in summer 2005 on a Hanford sandy loam soil at the USDA-ARS research center near Parlier, Calif. Telone-C35 (61% 1,3-D and 35% CP) was shank-applied to a depth of 46 cm with a spacing between shanks of 46 cm at a rate of 610 kg ha^{-1}. Small plots (9 x 9 m or 9 x 3 m depending on treatment) were used to test various surface-seal treatments that included control (no tarp and no water application), HDPE tarp, VIF tarp, pre-irrigated soil (56-mm depth of water applied to soil surface 48 h prior to fumigation) + HDPE tarp, initial water application (19-mm depth of water was sprinkled to dry soil surface immediately following fumigation), and intermittent water applications (initial 19-mm depth of water sprinkled immediately following fumigation + 4.2-mm depth of water each time sprinkled to soil surface at first sunset [8 h], 1st sunrise [22 h], noon [28 h], second sunset [32 h], and second sunrise [48 h] following fumigation). Treatments were tested with three replicates in a randomized complete block design. Emissions to the atmosphere and gas-phase distribution of fumigants in soil profile were monitored for nine days. Detailed information for this field trial is reported in Gao and Trout (in press).

The average emission rates of 1,3-D are shown in Fig. 2. Emission rates of CP (data not shown) showed similar pattern to that of 1,3-D except with lower values than 1,3-D. For both the control and HDPE-tarp-dry soil treatments, 1,3-D emission rates rapidly increased within the first 12 h (up to 40 μg m^{-2} s^{-1}) and reached maximum measured peak emission by 24 h. The peak emission rate for the control likely occurred during the first night when no samples were collected (indicated by the dash line in Fig. 1) and likely exceeded 80 μg m^{-2} s^{-1} for 1,3-D. The peak emission rate for the HDPE tarp over dry soil likely occurred early the second morning (about 22 h after fumigation). Initial water application immediately following fumigation again delayed fumigant emission for a few hours. This delay may be important in reducing risks to workers and bystanders during fumigation. Each water application following fumigation again showed abrupt reduction of emission rates but the emission rates, rebounded within three to four hours to approach those without water-application treatment. The VIF resulted in the lowest emission rates.

Total emission losses of 1,3-D and CP as percent of applied from surface-seal treatments over a 9-d monitoring period are given in Table 2. The control was not included in the comparison because no measurements during the first night after fumigation may have resulted in significantly underestimated error because total emission-loss estimate was much lower for the control compared to HDPE tarp. Among the surface-seal treatments, VIF and HDPE tarp resulted in the lowest and the highest total emission losses, 33% and 8% respectively. Intermittent water applications reduced 1,3-D and CP emissions significantly more than HDPE tarp alone and the initial water application only.

Overall, emission loss of CP is generally lower than 1,3-D. This may be due to the lower amount of CP applied as well as its more rapid degradation rate than 1,3-D. Surface treatments reduced CP emissions more than 1,3-D, except the initial water application treatment only. The emission loss by intermittent water seals was 30% of the HDPE tarp only for CP in comparison with 73% of HDPE tarp for 1,3-D. The pre-irrigated soil plus HDPE tarp reduced fumigant emissions effectively and also yielded the highest surface-soil temperature (data not shown) that may benefit overall soil pest control. However, tarps are an expensive alternative compared to water seals alone.

This field trial was conducted during hot days. Maximum and minimum air temperature ranged from 37–41^{o}C and 21–24^{o}C, respectively, during the field trial. Water application to soil surface illustrated the immediate effect on reducing emission rates, but intermittent water applications (five sprinkler applications after fumigation) did not significantly reduce 1,3-D emissions (24%) compared to the initial water application immediately following fumigation (27%). This may indicate that to compensate evaporation loss, more water may be needed for effective emission reductions.

Field Trial in Fall 2005

The objective of this field trial was to determine emissions from shank- and drip-applications of fumigants as well as surface-seal methods. In November 2005, we carried out a field trial on the same soil (Hanford sandy loam) as in the summer field trial in a peach replant orchard. Using plastic tarp is too expensive for most orchard growers in the Central Valley of California, as well as many vegetable growers. Telone products (Telone C35 for shank injection and InLine for drip irrigation) were applied (Table 3). Sampling and measurements for 1,3-D and CP emissions and distribution in the soil-gas phase were made for two weeks after fumigation. During the field trial, maximum and minimum air temperature ranged from 13-27^{o}C and 3-12^{o}C, respectively. Actual application rates for shank-injection were 20% higher than the drip applications (Table 3). Total emission losses were calculated as percent of applied, thus comparison of fumigant emissions between the fumigation methods should be valid.

The control resulted in the earliest and highest emissions (up to 76 μg m^{2} s^{-1}), followed by the HDPE tarp over shank injection (up to 70 μg m^{2} s^{-1}) (Figure 3). The emission peaks occurred at 15 h for the control and 48 h for the HDPE tarp after fumigation. Reasons for this difference are not apparent, but the results indicate that HDPE tarp is not effective in reducing 1,3-D emissions in a relatively cool fall season although emission peak may be delayed. Pre-irrigation for shank injection resulted in much lower peak emission rate than HDPE tarp (26 μg m^{2} s^{-1}). This illustrates that irrigation prior to fumigation can also more effectively reduce fumigant emissions than HDPE tarp. The VIF tarp resulted in large variations in emission rates (<1-26 μg m^{2} s^{-1}) in this field trial. Fumigation through drip application generally resulted in lower emission rates than shank injections. Emission rates of

CP showed similar trends as 1,3-D (data not shown), except with much lower values than 1,3-D. In addition, HDPE tarp-over-shank injection resulted in much lower CP emission rates than 1,3-D in comparison to the control. This indicates that HDPE is more effective in reducing CP emissions than 1,3-D.

Cumulative emission losses as percent of applied over a two week monitoring period after fumigation are shown in Figure 4 and Table 4. The control and HDPE tarp resulted in the earliest and highest 1,3-D emission loss in the first week, and emission loss from HDPE tarp exceeded the control after one week. Total losses of 1,3-D were 36% for the control (with large variation) and 43% for the HDPE tarp, respectively. Total emission losses from the pre-irrigation and VIF tarp-over-shank applications were about half of the control and HDPE tarp. Emission loss for VIF tarp-over-shank application was lower than the pre-irrigation initially but increased steadily up to the end of the monitoring. The VIF tarp can retain fumigants under the tarp, and degradation of the tarp permeability may be possible to cause emission increases in the later time. Drip applications with HDPE tarp and water applications before and after drip application resulted in the lowest and similar emission losses (12% and 13%, respectively for 1,3-D; and 2% and 3%, respectively for CP). This also indicates that that water applications before and after fumigation through drip irrigation can reduce emissions as effectively as HDPE tarp.

Total emission loss of CP generally follows similar pattern as 1,3-D except that HDPE tarp reduced CP emission more effectively than 1,3-D. Total losses of CP are generally lower than 1,3-D for the same treatment. This has been consistently observed and is mainly due to the differences between the two compounds. Chloropicrin has much lower vapor pressure (24 kPa or 18 mm Hg) than 1,3-D (45 kPa or 34 mm Hg) (Ajwa, 2003). Chloropicrin also has much shorter aerobic soil metabolism half-life than 1,3-D. For a sandy loam soil, the half-life of 1,3-D was 6.3 d (Dungan et al., 2001) compared to 1.5 d for CP (Gan et al., 2000) at 20^{o}C.

Results from the orchard field trial confirmed the ineffectiveness of HDPE tarp in reducing 1,3-D emissions. Irrigation to produce a moist-soil profile in the top 25-cm prior to soil fumigation effectively reduced 1,3-D and CP emission peaks and total emissions. The soil-water content was about 10% throughout the soil profile, which is about 60% of field capacity. In a Florida sandy soil, 1,3-D diffusion within the soil and emissions was greatly influenced by soil-water content (Thomas et al., 2003) where both diffusion and emission were minimal for saturated conditions, and very high in air-dry soil. With near-field capacity soil, the diffusion and emission fell between the two water regimes. This indicates that an optimum water content is needed for minimizing emissions while maintaining adequate efficacy. This optimum soil-moisture condition is not well defined. For fine-textured soils, the effect of water content on fumigant diffusion was most striking when soils had water contents in excess of 50 kPa moisture tension at 30 cm depth (McKenry and Thomason, 1974).

Conclusions

Results from soil-column tests and field trials have shown the effectiveness of water seals on emission reductions of 1,3-D and CP. Water seals can be more effective than HDPE tarp, thus offering a great opportunity in field applications. This effectiveness has been illustrated from sprinkler irrigation to soil-surface following fumigation as well as irrigation prior to fumigation. Water applications can clearly reduce emission peaks and delay emission times, thus providing benefit for reducing the risks to workers and by-standers during fumigation. Using water costs much less than HDPE tarp and is also environmentally friendly (no material disposal involved). Practices involved with irrigation to soil surface should be developed for field applications. Further research needs to determine the relationship between water content and fumigant distribution for different type of soils as diffusion of fumigants in soils becomes inhibited as soil-water content increases. Although fumigation through drip irrigation (with HDPE or water applications before and after fumigation) resulted in much lower emissions than shank fumigation in a field trial tested, mixed results have been reported. Thus it bears further investigations. Integrated research is needed to clearly define the optimum soil-water content for minimizing emissions as well as achieving adequate pest control.

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Table 1. Peak flux and 1,3-dichloropropene (1,3-D) total emission loss over 2 weeks from soil-column treatments.

Treatment[†]	Peak flux ($\mu g\ m^{-2}\ s^{-1}$)	1,3-D cumulative emission (% of applied)[a]
Control	15.7	50.6 (1.9)
Initial water (8-mm)	10.3	46.0 (1.3)
Initial water (8-mm) + 2.6 mm at 12 h	8.2	44.5 (0.9)
Initial water (8-mm) + 2.6-mm at 12 h + 2.6-mm at 24 h	7.5	41.0 (2.2)
High-density polyethylene (HDPE)	10.2	44.0
Initial water (8 mm) + HDPE	8.6	37.0
Virtually impermeable film (VIF)	1.3	9.6

[a] Values in parentheses are standard deviations of duplicate-column measurements.

Table 2. Total emission loss of 1,3-dichloropropene (1,3-D) and chloropicrin (CP) for surface-seal treatments measured over 9 d after fumigation in summer 2005 field trial on a Hanford sandy loam soil near Parlier, Calif.

Treatment	Total loss (% applied)[a]	
	1,3-D	CP
High-density polyethylene (HDPE)	33.0 (a)	9.2 (a)
Virtually impermeable film (VIF)	7.5 (c)	1.2 (c)
Pre-irrigated soil + HDPE	22.1 (b)	2.8 (b, c)
Initial water application	26.5 (a, b)	8.0 (a, b)
Intermittent water applications	24.2 (b)	3.2 (b, c)

[a] Within a column, means (n=3) with the same letter in parentheses are not significantly different (α=0.05).

Table 3. Fumigation and surface treatments for emission study in fall 2005 field trial on a Hanford sandy loam soil near Parlier, Calif.

Fumigant[a]	Application[b] Method	Application rate[c] (kg/ha)	Soil seal methods[d]
Telone C-35	Shank	745	Control (dry soil, disk, harrow)
Telone C-35	Shank	745	HDPE (dry soil, disk, harrow)
Telone C-35	Shank	745	VIF (dry soil, disk, harrow)
Telone C-35	Shank	745	Pre-irrigate (~40 mm water sprinkler applied, disk, harrow)
InLine	Drip	629	HDPE
InLine	Drip	629	Water applications (8-mm water pre- and post-fumigation)

[a] Telone C35: 61% 1,3-D, 35% CP, 4% inert ingredients; InLine: 61% 1,3-D, 33% CP, 6% inert ingredients.
[b] Fumigants were applied in strips (strip width was 3.7 cm for shank injection and 3.2 m for drip application). All shank treatments were disked and harrowed following fumigation. (Telone products were applied 46 cm deep with seven shanks spaced 46 cm apart. For drip-applied treatments, drip tapes (30 cm emitter spacing) were installed 20 cm below the soil surface on 46 cm spacing. InLine was applied with 15 cm of irrigation water over 25 h.
[c] This was the actual application rate, which was about 20% higher than the target rate for shank injection.
[d] For pre-irrigation - shank treatment, strips were pre-irrigated with micro-spray sprinklers four days before fumigation to achieve near-field capacity, soil-water content to a 25-cm depth. For the water caps in drip-fumigation treatment, 12 mm of sprinkler irrigation water was sprinkled just before and following application. Tarps were applied after shank injection and before drip application. Duplicate measurements were made for each treatment.

Table 4. Total emission loss of 1,3-dichloropropene (1,3-D) and chloropicrin (CP) measured over 2 weeks after fumigation in fall 2005 field trial on a Hanford sandy loam soil near Parlier, Calif.

Treatment	1,3-D	CP
	----------------(% of applied)-------	
Control (shank - Telone C35)	36.1 (7.1)	30.4 (2.9)
Shank - Telone C35 - HDPE	43.0 (0.4)	16.9 (0.0)
Shank - Telone C35 - VIF	18.7 (0.7)	7.9 (0.1)
Shank - Telone C35 – pre-irrigation	19.2 (0.5)	8.8 (0.2)
Drip - InLine - HDPE	12.3 (2.3)	2.0 (0.4)
Drip – InLine - water applications pre- and post-fumigation	12.7 (4.7)	2.9 (1.5)

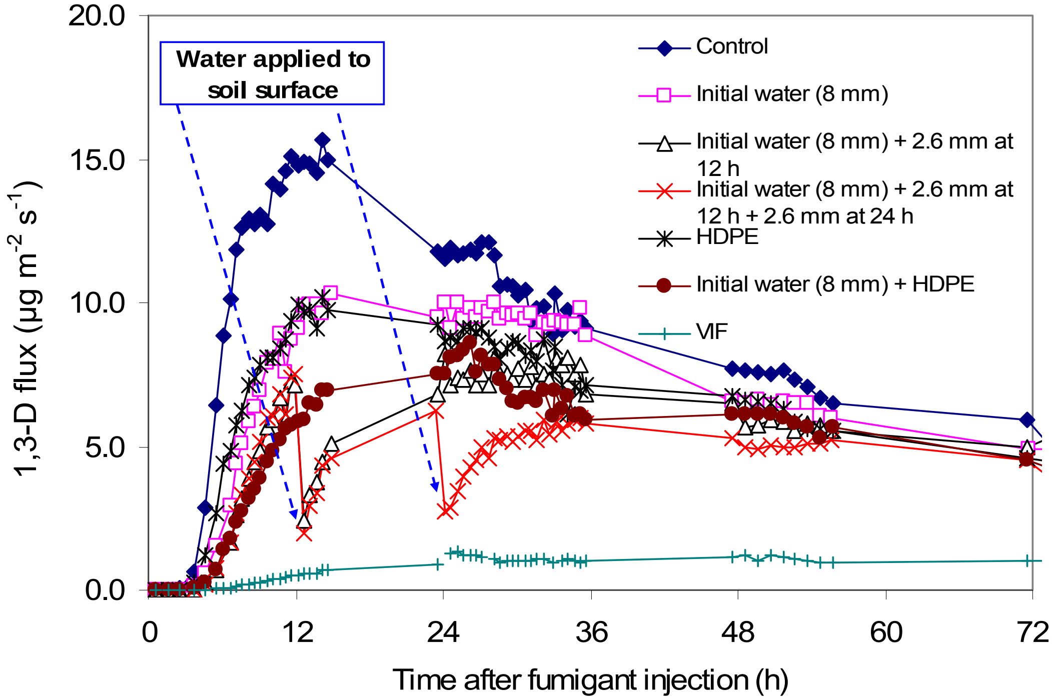

Figure 1. 1,3-dichloropropene (1,3-D) emission rates from soil-column treatments (Gao and Trout, 2006).

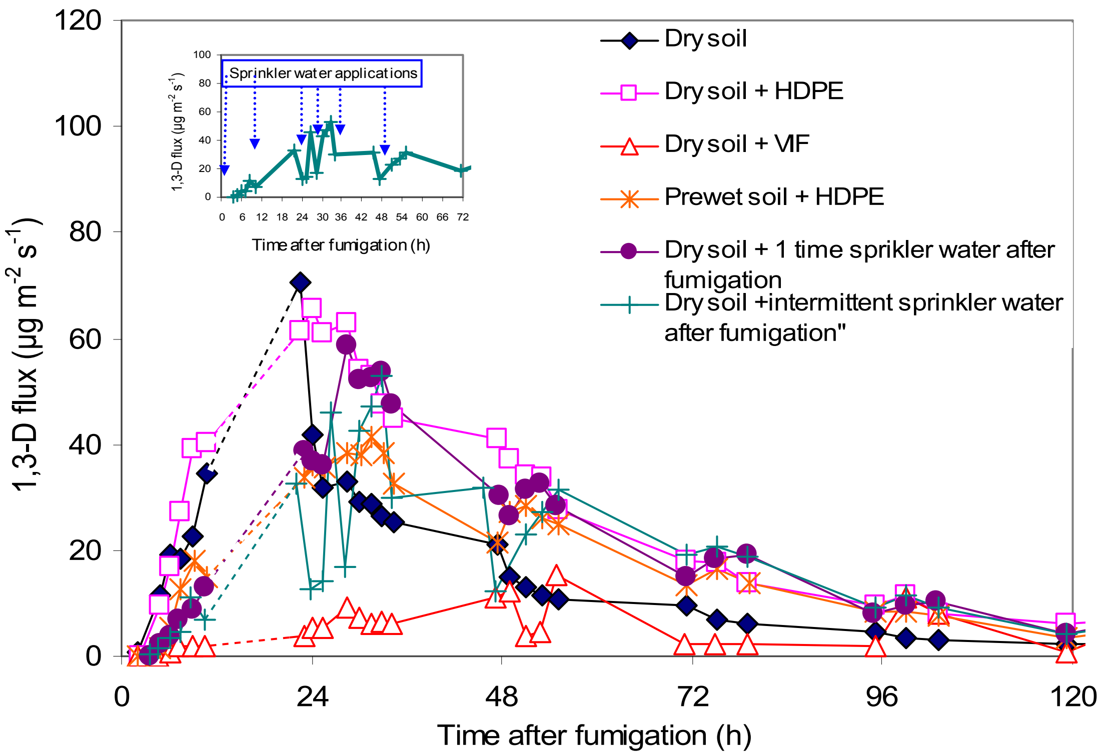

Figure 2. Effects of surface-seal treatment on emission flux of 1,3-dichloropropene (1,3-D) after shank injection of Telone C35 in summer 2005 trial on Hanford sandy loam soil. Plotted data points are the means of three replicates. Dashed lines indicate that no measurements during this period of time resulted in uncertainties. The intermittent water-application events on emission rates were shown in the sub-figure.

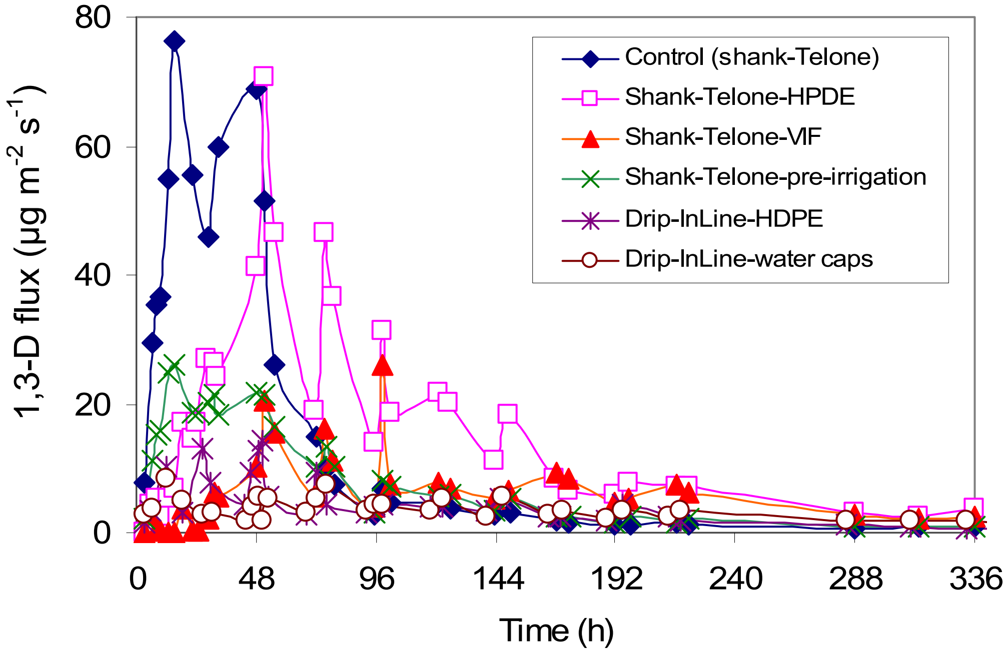

Figure 3. Effects of application methods and surface-seal treatments on emission flux of 1,3-dichloropropene (1,3-D) from Telone C35 (shank-injection) and InLine (drip-irrigation) applications in fall 2005 orchard field trial on Hanford sandy loam soil. Plotted data are averages of duplicate.

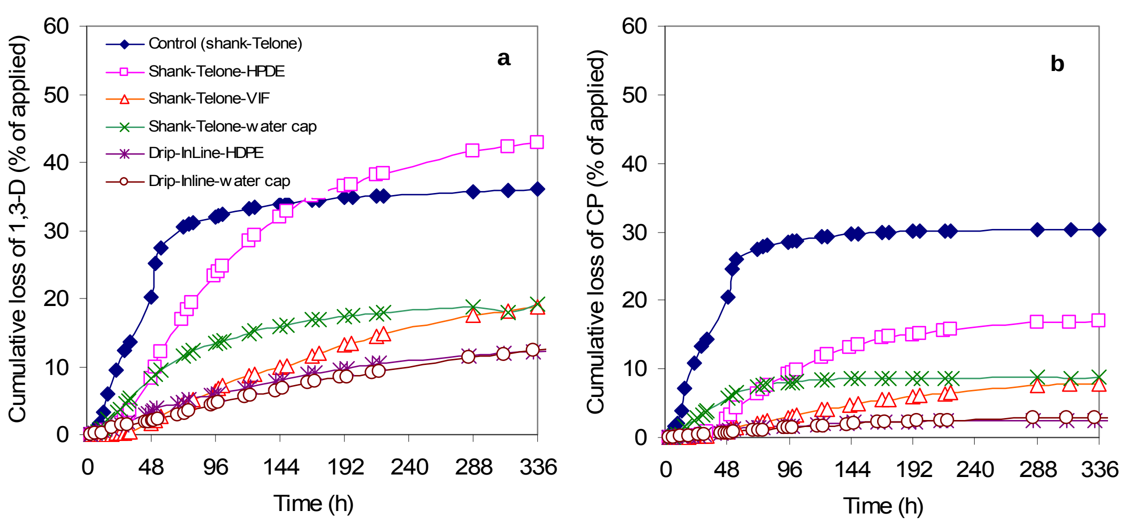

Figure 4. Cumulative emission of (a) 1,3-dichloropropene (1,3-D) and (b) chloropicrin (CP) from surface-seal treatments from fall 2005 orchard field trial on Hanford sandy loam soil. Plotted data are averages of duplicate.

EVALUATING THE ECONOMIC IMPACT OF ELIMINATING FUMIGATION IN THE SAN JOAQUIN VALLEY: CARROTS AND ONIONS

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Abstract
Fumigants are an important source of volatile organic compounds in California's San Joaquin Valley. This study estimated revenue and profit losses associated with the loss of fumigants for carrot and onion production in the San Joaquin Valley. Based on these loss estimates, we calculated the cost to producers per ton, per peak season day, of VOC emission reduction using available price, yield, acreage, and production cost information. While we obtained a range of estimates, the most plausible ones given the available information suggested annual revenue losses per ton/day of $6 million to $7 million for carrots, and about $17 million to $24 million for onions; and suggested annual profit losses of approximately $1 million or less for carrots, and roughly $4 million to $6 million for onions.

Key words: volatile organic compounds, fumigation, carrots, onions

NON-CHEMICAL ALTERNATIVES TO FUMIGATION FOR POST-HARVEST DRIED FRUIT AND NUTS

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Abstract

Nearly all dried fruit and nuts in the United States are grown in central California. Each year this diverse industry yields 1.5 million metric tons of product, worth about $2 billion, with exports constituting 45% of the market. Infestation by post-harvest insects are a serious problem, usually requiring disinfestation treatments before distribution of product. Fumigants have been the treatment of choice in many cases, but environmental and regulatory concerns over their continued use have generated interest in non-chemical alternatives. Identifying potential applications for non-chemical methods requires familiarity with processing and storage methods as well as marketing constraints within the industry. Although no single non-chemical alternative could serve as a direct substitute for fumigation, use of non-chemical treatments for specialized applications would substantially reduce fumigant use. For these reasons, radio-frequency heat treatments and vacuum treatments were evaluated as potential alternatives. Radio-frequency treatments were found to have great promise for use in in-shell walnuts, while vacuum treatments are more suitable for smaller volumes of bagged-tree nuts.

Key words: dried fruits, tree nuts, fumigant alternatives, radio frequency, vacuum

Introduction

California produces nearly all of the dried fruit and nuts in the United States, resulting in an annual production of nearly 1.5 million metric tons of commodity, valued at more than $2 billion (Table 1). Nearly half of California's dried fruit and nut production is exported to foreign markets (Table 2). A major problem in the storage and marketing of dried fruit and nuts is infestation by various insects. Feeding insects damage the product directly, and also contaminate the product with webbing, feces, and cast skins. As dried fruit and nuts are often used in confectionary goods or eaten out-of-hand as snack foods, there is no tolerance for live insects. Infestations often cause customer returns and loss of consumer confidence, and may result in legal or regulatory actions.

Conventional processors rely heavily on chemical fumigants, particularly methyl bromide and hydrogen phosphide, to control post-harvest insect infestations. Recent regulatory actions have restricted use of methyl bromide to quarantine applications, requiring industries to apply for yearly Critical Use Exemptions to continue to use the fumigant for other applications (UNEP, 1992). Insects may develop resistance to hydrogen phosphide (Zettler et al., 1989), and there are worker safety issues concerning this fumigant (USEPA, 2001). In addition, the rapidly growing market for organically grown dried fruit and nuts demands control methods that are compatible with organic standards. Because of these issues, there is a growing interest in finding non-chemical alternatives to fumigation for dried fruit and nuts.

A variety of insects are responsible for post-harvest infestations in dried fruit and nuts. Pre-harvest field pests that feed directly on the fruit or nut may be present in the product at the time of harvest and brought into storage. These pests generally do not reproduce under storage conditions, but they may continue to feed, and often present phytosanitary problems for exporters. Feeding damage by these insects in tree nuts may also provide entry to aflatoxin-producing fungi (*Aspergillus* spp.). Two of the most important field pests of post-harvest significance are codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), and navel orangeworm, *Amyelois transitella* (Walker) (Lepidoptera: Pyralidae).

Dried fruit and nuts are also susceptible to attack by common stored-product insects. These insects rarely are found in the field but reproduce well under storage conditions. The Indianmeal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), is the most important storage pest on the products, and is responsible for the majority of customer returns. Another important storage pest of post-harvest dried fruit and nuts is the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae).

The dried fruit industry in California is a large and diverse mixture of co-operatives, individual processors of various sizes, and marketing orders. Storage facilities and methods depend upon the product and individual processor, and range from outdoor bin stacks or silos to refrigerated warehouses. Although California dried fruit and nuts require some degree of dehydration, the exact method varies from sun-drying (most almonds, raisins, and figs) to use of hot forced air (walnuts, pistachios, dried plums). Because of the diversity of drying, processing, and storage methods used in the California dried fruit and nut industry, it is unlikely that a single non-chemical alternative will be suitable for all possible applications. Consequently, the USDA-ARS Dried Fruit and Nut Insect Laboratory (DFNIL) in Parlier, Calif. has been working on a variety of non-chemical alternatives, including combination treatments (Johnson et al., 1998; 2002), low-temperature storage (Johnson et al., 1997) and biological control using parasitoids (Johnson et al., 2000).

Two other approaches of interest are radio-frequency (RF) heat treatments and vacuum treatments. A team of collaborators, including researchers from Washington State University, Pullman, Wash., the University of California, Davis, Calif., and the DFNIL have shown the potential of RF treatments to disinfest in-shell walnuts of post-harvest insect pests (Wang et al., 2002c; Mitcham, et al., 2004). RF treatments use electromagnetic energy at radio frequencies between 10-100 MHz to volumetrically heat products to control insects. It can be designed as continuous treatments for large volumes or as batch treatments in small operations. Vacuum treatments make use of inexpensive, flexible storage containers capable of maintaining very low pressures to treat stored commodities, killing insects through a combination of anoxia and dehydration. This paper summarizes recent research into these two methods.

Procedures

Radio-Frequency Treatments: Using information developed in thermal-death kinetic studies (Wang et al., 2002a,b; Johnson et al., 2003; 2004), an RF treatment which produced a minimum kernel temperature of 52°C for 5 minutes, was developed to control insect pests in in-shell walnuts. The treatment was tested under commercial conditions at the Diamond Walnut processing plant in Stockton, Calif. using a 27.12-MHz industrial-scale, 25-kW RF system. Laboratory-reared fifth-instar navel orangeworm, which had previously been identified as the most heat-tolerant species and stage (Fig. 1), were selected as test insects. RF treatments were applied to walnuts either before test walnuts were washed or after walnuts were washed and air-dried. To obtain a full load for each treatment, 17 plastic containers with perforated bottoms and side walls, each filled with 11 kg of walnuts, were sent through the RF unit. Containers #9 and #12 also included 75 walnuts, which had been artificially infested with test larvae shortly before treatment (Wang et al., 2002c). After each treatment, samples of non-infested nuts were collected for quality determination by the Quality Assurance Laboratory at the Diamond plant. Quality evaluations were made immediately after treatment and after 10 and 20 days under accelerated storage conditions, equivalent to one and two years under commercial storage conditions. The main quality parameters of concern were peroxide values (PV, meq/kg), fatty acids (FA, % oleic), and kernel color. Moisture contents of shell, kernel, and whole walnut were also measured.

Vacuum Treatments: Because preliminary studies showed that the presence of commodity may affect the efficacy of vacuum treatments, we developed a laboratory bioassay using cylindrical stainless steel vacuum chambers partially filled with nuts. Using this method, we estimated the exposure times necessary for 95% mortality (LT_{95}) of test insects at 50-mm Hg at 25 and 30°C for navel orangeworm eggs and larvae, codling moth eggs, diapausing larvae and non-diapausing larvae, and Indianmeal moth eggs and diapausing larvae. Pupae of all three moth species were found to be very sensitive to the treatments and were not included in the study.

Two series of field studies using almonds were done using five-metric-ton GrainPro Cocoons, sturdy plastic bags that were sealed with a zip-lock mechanism. Vacuum pressures were obtained with a Becker U 4.70 SA/K vacuum pump. The first field study was done under winter conditions, using shelled almonds in wooden bins. Test insects were diapausing codling moth, diapausing Indianmeal moth, navel orangeworm larvae, Indianmeal moth eggs, and navel orangeworm eggs. Diapausing codling moth larvae were included because of their importance to in-shell walnut exports, even though they are not a pest of almonds. The second series of tests was done under summer conditions using in-shell almonds in 22.7 kg poly bags. Test insects were diapausing codling moth, diapausing Indianmeal moth, Indianmeal moth eggs, and navel orangeworm eggs. For all field studies, test insects were placed in sturdy, ventilated containers and hidden within the almonds.

Results

Radio-Frequency Treatments: Table 3 shows the average walnut kernel and walnut surface temperature for each of the five replicates (three with unwashed nuts and two with washed and air-dried nuts). Minor differences in final temperatures were due primarily to normal variability in walnut moisture content. There were no significant differences between final temperatures of unwashed and washed nuts. In all RF treatments, all test larvae were killed, while mortality in untreated control larvae was very low (<1.1%).

The quality of RF-treated walnuts was very similar to untreated product. Quality parameters of peroxide values, fatty acid levels, and kernel color were all within those ranges required by the industry for good product quality. This was true even after accelerated storage of 20 days, simulating two years of commercial storage. Moisture content was the parameter most affected by RF treatment. The moisture content of walnut shells was reduced from an average of 7.3% to 6.3% after RF treatment. Kernel moistures were less affected, being reduced from 3.3% to 3.0% after treatment. Moisture contents after RF treatment were considered to be acceptable by industry standards.

Vacuum Treatments: Laboratory studies identified diapausing larvae and the egg stage as the most tolerant life stages. The exposure times needed for 95% mortality (LT_{95}) for these stages for codling moth, Indianmeal moth, and navel orangeworm is given in Table 4. Navel orangeworm does not have a known diapausing larval stage, so only navel orangeworm eggs are included. The mode of action for vacuum treatments is thought to be due in part to anoxia from reduced oxygen; consequently, treatments are temperature dependent. LT_{95} values at 30°C were considerably shorter than those at 25°C. At both temperatures, the most tolerant stage was navel orangeworm eggs.

Another mode of action for vacuum treatments is dehydration. Weight measurements over time of codling moth larvae treated at 50-mm Hg and 25°C showed considerable weight loss when compared to controls (Fig. 2). Although average weight loss was nearly 40% after 8-10 hours of vacuum treatment, no mortality in test larvae was observed.

Results of field studies using vacuum under GrainPro Cocoons are given in Table 5. The first three trials with shelled almonds in wooden bins were done during the winter, when average temperatures were 10°C or below. Because of these low temperatures, long exposures were necessary to obtain control of the more tolerant insect stages. Non-diapausing navel orangeworm larvae are relatively susceptible to vacuum and complete mortality of this stage was obtained with exposures as short at seven days. Relatively high mortalities of both navel orangeworm and Indianmeal moth eggs were obtained after seven days of exposure, but due to the low temperatures, control mortality of these stages was also high. Diapausing codling moth larvae were the most tolerant to the treatment, with some survival occurring after 13 days of exposure.

Field trials with in-shell almonds in 22.7-kg bags were done during the summer, when average temperatures were 25°C or above. Complete mortality was obtained for all test insects after two days of exposure. After one and a half days, some survival of navel orangeworm eggs was found. Survival occurred in all stages after one day of vacuum exposure, particularly in the diapausing Indianmeal moth and codling moth larvae.

Discussion

No single non-chemical treatment is a suitable alternative for all the chemical fumigation done in California's large and diverse dried fruit and nut industry. However, alternatives such as RF heating and vacuum show potential in specific applications. RF heating is an established technology that is used in numerous industries, and equipment suitable for food processing is readily available. Because RF heating is a rapid treatment, it can handle the large volumes common in the dried fruit and nut industry. While there would be a substantial initial capital investment for equipment and plant infrastructure, we found the energy costs for the walnut RF treatment to be comparable to the current cost of methyl bromide.

Vacuum treatments applied in low-cost flexible containers are best suited to treat product in bags. Wooden bins commonly used in California for dried fruit storage are more difficult to treat, and may buckle under the pressure. Loading the vacuum containers with product may result in an increase in labor costs. Consequently, vacuum treatments may be more suitable to use with smaller volumes of bagged tree nuts. Our field studies show that vacuum treatments applied when ambient temperatures are above 25°C can provide good control after two days of exposure, a treatment time that is comparable to that of phosphine.

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Table 1. Five-year average (2000-2004) production and value for California dried fruit and nuts. [1]

Commodity	Production (metric tons)	Value ($ million)
Almonds	474,291	1,279
Walnuts	300,140	360
Pistachios	119,182	270
Dried Plums	145,295	117
Raisins	400,770	466
Figs	15,850	17
Total	**1,455,528**	**2,509**

[1] Compiled from USDA, 2005

Table 2. Five-year average (2000-2004) rank and value for California dried fruit and nut exports. [a]

Commodity	Rank	Value $ million	% Crop Exported
Almonds	1	926	67
Walnuts	9	197	40
Raisins	13	160	32
Dried Plums	14	136	70
Pistachios	15	130	40
Figs	44	8	19
Total value dried fruits and nut exports			**$1.56 billion**
Percentage total dried fruit and nut crop exported			**45%**
Percentage total California agricultural exports			**22%**

[a] Compiled from UC AIC, 2004 and USDA, 2005

Table 3. Average nut kernel temperature, nut surface temperature, and insect mortality in radio-frequency treated, in-shell walnuts. [1]

Rep	Treatment	Average temperature (°C)		% Insect mortality
		Kernel	Nut surface	
Unwashed walnuts				
1	RF	58.5	63.8	100
	Control	26.0	27.8	0
2	RF	57.9	62.6	100
	Control	23.7	22.7	1.1
3	RF	55.9	59.2	100
	Control	24.3	23.9	0
Washed and air-dried walnuts				
1	RF	59.7	66.5	100
	Control	28.6	27.5	1.0
2	RF	57.6	60.4	100
	Control	27.8	28.3	0

1 Each replicate consisted of two, full-load runs done on the same day. Each run included temperature measurements from two containers (#9 and #12). Nuts in each of these two containers included 75 infested walnuts.

Table 4. Lethal times (hours) for 95% mortality of the most tolerant life stages of common dried fruit and nut pests treated under vacuum at 50 mm Hg and 25°C or 30°C.

Species and Life Stage	**LT_{95} (hours)**	
	25°C	**30°C**
Diapausing codling moth larvae	30.0	15.2
Diapausing Indianmeal moth larvae	35.4	17.5
Codling moth eggs	27.6	21.1
Indianmeal moth eggs	33.4	18.7
Navel orangeworm eggs	36.9	26.1

Table 5. % Insect mortality in field tests treating shelled and in-shell almonds in GrainPro Cocoons under vacuum to control navel orangeworm (NOW), Indianmeal moth (IMM), and codling moth (CM).

Treatment	Eggs			Diapausing larvae			Larvae
	NOW	IMM		IMM	CM		NOW
Shelled almonds; 7 days at 43.1 mm Hg and 10.5°C							
Control	46.2	17.6		2.4	1.6		13.0
Vacuum	99.0	97.4		96.8	75.1		100.0
Shelled almonds; 9 days at 38.5 mm Hg and 8.9°C							
Control	98.8	100.0		1.0	0.5		0.7
Vacuum	100.0	100.0		88.3	1.5		100.0
Shelled almonds; 13 days at 17.7 mm Hg and 6.3°C							
Control	100.0	100.0		2.6	0.5		4.0
Vacuum	100.0	100.0		100.0	99.5		100.0
In-shell almonds; 2 days at 50 mm Hg and 29.5°C							
Control	71.4	63.3		3.3	0.0		-
Vacuum	100.0	100.0		100.0	100.0		-
In-shell almonds; 1.5 days at 50 mm Hg and 27.0°C							
Control	17.9	2.3		0.0	0.0		-
Vacuum	98.2	100.0		100.0	100.0		-
In-shell almonds; 1 day at 75 mm Hg and 25.0°C							
Control	16.7	2.7		0.0	1.5		-
Vacuum	96.8	97.0		25.7	21.1		-

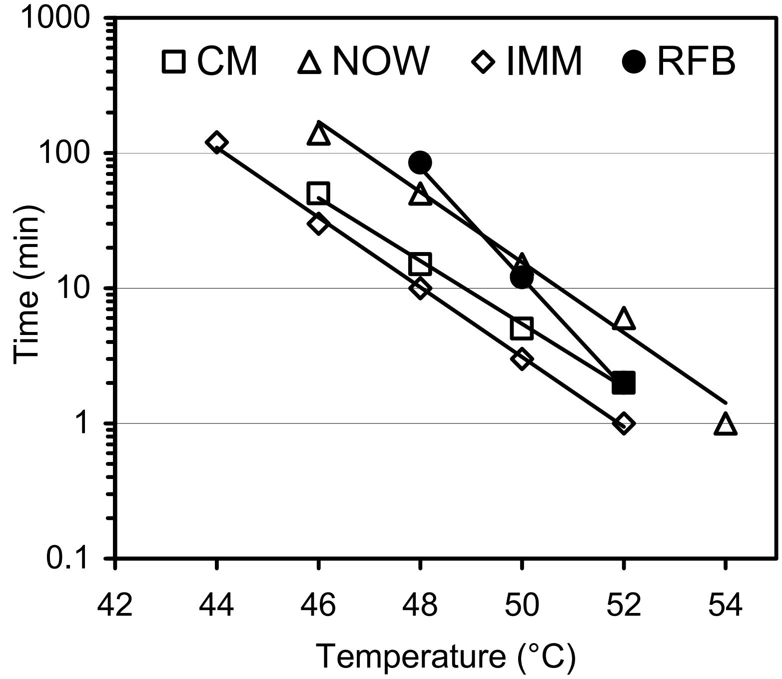

Figure 1. Thermal-death curves for four common post-harvest pests of California dried fruit and nuts.

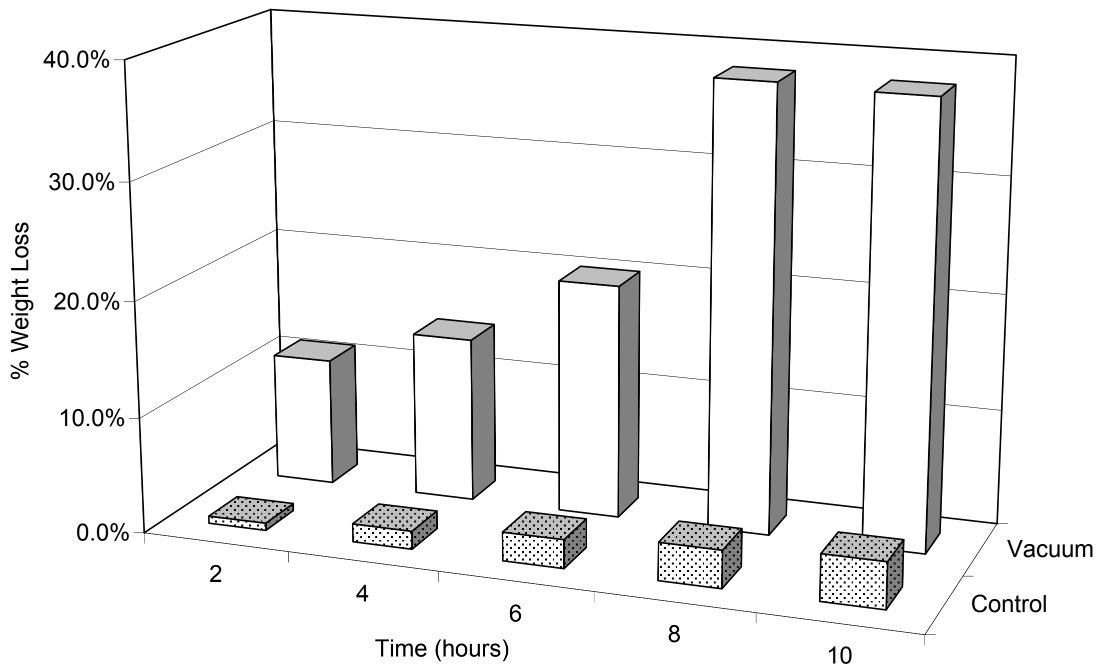

Figure 2. Weight loss over time of codling moth larvae treated at 50 mm Hg and 25°C.

DEVELOPMENT AND VALIDATION OF PREDICTIVE MODELS OF SOIL HEATING AND PATHOGEN INACTIVATION DURING SOIL SOLARIZATION

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Abstract
Methyl-bromide fumigation is common practice for control of soilborne pathogens, nematodes, and weeds; however, its use contributes to significant stratospheric ozone depletion. Soil solarization is a non-chemical alternative to fumigation. In solarization, moist soil is covered with a transparent plastic film, resulting in passive solar heating of the soil. This inactivates pathogens and weeds and selects for beneficial microorganisms during soil recolonization that outcompete pathogens. Despite its effectiveness, soil solarization is not widely used because current recommendations are for solarization during the time in which crops are produced, thereby causing a loss in income. The goal of our research is to better understand the heat transfer and microbial community dynamics during soil heating so that recommended solarization periods are more flexible and predictable. Field and laboratory solarization studies were conducted to investigate changes in soil microbial communities, measured by phospholipid fatty acid analysis, during solarization. Soil organic matter and exposure to thermophilic temperatures had a significant effect on microbial community structure. Furthermore, models were developed to represent inactivation of the fungal community, a source of potential plant pathogens due to soil heating, and to estimate soil temperature from real-time weather data.

Key words: soil solarization, pathogen control, weed control, mathematical modeling

THE POTENTIAL OF NEMATODE RESISTANT CARROTS TO REDUCE SOIL FUMIGATION AND VOC EMISSIONS

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Abstract

Carrots are the crop with the highest contribution to VOCs (c. 20%) in the San Joaquin Valley and southern desert in California, due to the amounts of soil fumigants used. Preplant fumigation with metam-sodium or 1,3-dichloropropene is used for nematode control primarily and possibly pathogen control. We have developed advanced, fresh market carrot breeding lines with excellent root-knot nematode resistance that will become available to growers in new varieties within the next few years. The resistance is conferred by a major gene, *Mj1*. On-farm experiments are being conducted to assess the benefits of resistant carrots, as an alternative to soil fumigation. Field experiments are designed using split-plot comparisons of resistant and susceptible carrots each grown on preplant-fumigated and non-fumigated plots. In addition to nematode infection and soil population levels, carrots are being monitored for occurrence of other root pathogens and growth constraints that may be present under non-fumigation conditions. In two Kern County fields in 2005, resistant carrots blocked nematode infection and injury and no other pathogens were found affecting carrots in non-fumigated plots. The goal is to determine the effectiveness of growing resistant carrots with reduced rate or no fumigation, thereby offsetting soil fumigation needs and reducing VOCs.

Key words: carrots, nematodes, host resistance, soil fumigants, volatile organic compounds.

A TEN-YEAR CASE STUDY OF A LOGICALLY INTEGRATED FARMING SYSTEM FOR WINEGRAPES IN LODI, CALIFORNIA

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Abstract
The Lodi-Woodbridge Winegrape Commission (LWWC) was awarded the University of California's first biologically integrated farming systems (BIFS) grant in 1996. The BIFS program became the foundation of LWWC's sustainable winegrowing program and is in its 10th year. Forty growers, who manage 40% of the 90,000 vineyard acres in the Lodi region, participated in the program, designating 70 vineyards (2500 acres) as BIFS vineyards and implementing a range of sustainable farming practices in them. All farming practices implemented in these vineyards were tracked using a relational database, including weekly pest monitoring, pesticide use, fertilizer use, vineyard floor management, canopy management, and yield. Data summaries from the BIFS vineyards were shared annually among all BIFS growers, and BIFS vineyards were focal points for field days for the rest of the 750 LWWC winegrape growers. Surveys of the entire LWWC membership were carried out in 1998 and 2003 to measure effects of the BIFS program on farming practices of all LWWC growers. The BIFS program resulted in LWWC publishing a self-assessment workbook for sustainable winegrowing in 2000. It was used by more than 350 LWWC growers. Creation of a third-party sustainable certification program was launched in 2005.

Key words: BIFS, sustainable agriculture, grower outreach, farmer-to-farmer education

TRACKING GROWER ADOPTION OF A NEW STONE FRUIT PEST MANAGEMENT PROGRAM

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Abstract
California peach and nectarine growers used more than 6 million pounds of pesticides in 2004. Water and air quality concerns continue to force growers to consider alternatives to conventional pest management practices. Studies begun in 2004 focused on reducing or eliminating unnecessary pesticide applications and worked with growers willing to adopt new monitoring and treatment thresholds. A tree fruit seasonal guide describing these pest management strategies was published as a resource for growers. In addition, a study group of 54 large-acreage growers within 30 miles of Parlier, California, was identified who averaged 3.2 lbs per acre of five pesticides (chlorpyriphos, phosmet, carbaryl, methidathion, and diazinon). A 20% reduction in pesticide use among these growers was considered attainable if growers followed the seasonal guide and used available technology with critical pesticide applications. Meetings in growers' orchards will be used for hands-on demonstration of the seasonal guide, to allow for grower-to-grower exchange of information and to familiarize growers and influential pest control advisors with new technology that could be used to reduce pesticide use. Grower acceptance of the seasonal guide will be tracked with a survey and California pesticide use reports for the Parlier study group.

Key words: stone fruits, pesticides, FQPA, ecosystem health, technology applications, IPM

INCREASING BIOLOGICAL RELIANCE IN SAN JOAQUIN VALLEY COTTON: MEETING ENVIRONMENTAL AND CONSUMER CHALLENGES

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Abstract

Environmental concerns are driving production issues in California cotton production. Cotton producers and field consultants, together with the Sustainable Cotton Project and University of California Cooperative Extension, are taking the lead in continuing to move production and pest management practices toward more biologically intensive practices. These practices incorporate intensive weekly sampling to measure population densities of insect pests and natural enemies, introduction of lacewings, intercropping of alfalfa hay or other predator habitats, and choosing reduced-risk insecticides. University of California Cooperative Extension is a partner in this effort and provides research, and technical and outreach support. This includes assessment approaches and year-round IPM best management practices (http://www.ipm.ucdavis.edu/PMG/C114/cotton-checklist.pdf). The compilation of practices is labeled BASIC practices (Biological Agriculture Systems in Cotton, www.caff.org/programs/farmscaping/Cotton%20Manual.pdf) and has resulted in a reduction of pesticides as compared to county average use, especially those listed as high risk to water quality and human health. Current efforts include exploring organic Pima cotton production and development of a premium for BASIC-produced cotton lint.

Key words: year-round IPM, sustainable cotton production, participatory extension, product premium

BEGINNING WITH HEALTHY PLANTS: THE CORNERSTONE OF INTEGRATED PEST MANAGEMENT FOR PERENNIAL CROPS

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Abstract

Perennial clonally propagated crops are subject to many graft-transmissible diseases caused by viruses, viroids, and systemic prokaryotes. Many of these crops, such as citrus, have the potential to be productive for decades. Use of a certification program which incorporates a quarantine program to ensure the safe introduction of select horticultural germplasm, a clean stock program to conduct testing and provide therapy to identify and produce sources of pathogen-free propagating stock, and a certification program to ensure the development and maintenance of pathogen-free propagating materials for commercial use help ensure that healthy plants of the highest horticultural potential are grown. The cost-benefit ratio of certification programs is very favorable, and certification programs are important to prevent the introduction of additional pathogens. Specific examples will be given using citrus as an example.

Key words: IPM, citrus, certification programs, graft-transmissible pathogens

Introduction

Many perennial crops may have a long, productive lifespan when good horticultural care is given and diseases are avoided. For example, the parent Washington naval tree was originally received and planted in California in 1873 (Hodgson, 1967). In 1910, one of the three original trees was replanted to its present location at the intersection of Arlington Ave. and Magnolia Blvd. in downtown Riverside, California, where it is still a healthy and growing 140-year-old tree. Since it was originally a cutting budded on sweet orange rootstock, the tree was beginning to die from phytophthora root rot. It was inarched with a number of phytophthora-tolerant rootstocks and it survives today. A second sister tree planted at a location that is now called the Mission Inn did die due to phythphthora. The original parent Washington naval tree was free of graft-transmissible pathogens, and propagations from the parent tree set fruit within a couple of years after its import into California. Up to this time, oranges were grown from seed in California; the fruit contained many seed and the seedling trees underwent a juvenility phase of upright growth, excessive thorniness, and delayed fruit production of six to eight years. Advantages of clonal propagation using buds became apparent, and it became common place to clonally propagate from productive trees to a desirable rootstock.

Because the practice of clonal propagation of citrus and other perennial crops began before the presence of graft-transmissible pathogens was generally recognized, many of these graft-transmissible pathogens found a happy home in their perennial hosts and have been passed from generation to generation through vegetative propagations. Presence of certain viruses has precluded usage of some rootstocks for citrus. For example, when Meyer lemon was first imported from China, it was noted that propagations on sour orange and poncirus trifoliate rootstock failed. We now realize this was because the original importations of Meyer lemon were infected with citrus tristeza and citrus tatterleaf viruses which prevented the use of sour orange and poncirus trifoliate rootstocks, respectively (Lee et al., 1997). The realization that some of the declines that reduced tree vigor and productivity were caused by graft-transmissible pathogens began in the late 1930s when the graft-transmissible nature of citrus psorosis was discovered (Fawcett, 1938). This discovery of the graft-transmissible nature of some citrus diseases, such a psorosis, led to development of methods to limit destructiveness of graft-transmissible pathogens by preventing their occurrence in trees used for budwood for the propagation of additional trees. Thus, the concept of certification programs based on exclusion of graft-transmissible pathogens was born.

Certification Programs

Certification programs provide the basic platform for all integrated pest management practices of citrus (Lee et al., 1999). Management of insect and fungal pests in the nursery prevents widespread distribution of these pests into the field and lessens the need for chemical applications for control of these pests even after the citrus plants have been planted in the field. Control and management of chronic-decline diseases such as huanglongbing (HLB), more commonly known as citrus greening, and citrus-variegated chlorosis (CVC) caused by a strain of xylella fastidiosa, begins with the production of healthy trees to plant in the field (Buitendag and von Broembsen, 1993; Rosetti, 2000). Horticultural evaluations, or variety trials, planted primarily to verify horticultural trueness-to-type as a part of the certification program, provide valuable yield and fruit quality information to enable the growers to select the most productive clones for planting in their groves, thus ensuring they have healthy trees of the highest genetic potential.

The term "certification program" is often misused to refer only to a clean stock program which, if used as a propagating source, would enable propagation of clean nursery plants. A true certification program is composed of three separate, but well integrated, programs (Lee et al., 1999). The three are 1) a quarantine program to provide for the safe introduction of select exotic horticultural germplasm, 2) a clean stock program for the testing and therapy to produce pathogen-tested germplasm for commercial use from domestic germplasm, and 3) a certification program which maintains the pathogen-tested germplasm sources and provides the mechanism to distribute them to nurseries and growers to benefit the industry. The pathogen-tested (healthy) plants from the quarantine and the clean stock programs provide the necessary material for the certification program.

Quarantine Programs

Growers are always looking for new varieties which might have appeal in the marketplace or which may give them a competitive edge (Roistacher, 1993), for example, earlier or later maturing varieties which may extend the market season, deeper fruit color, unique fruit shape, seedlessness, or tolerance to a disease. Plant breeders need exotic cultivars and varieties for use in plant breeding. There is always a demand for exotic germplasm. Uncontrolled importation of exotic germplasm can result in importation of new pests and pathogens, some of which could cause great economic losses to the whole industry. These risks may be minimized by carefully controlled introduction of exotic germplasm through quarantine stations which allow for therapy of the new germplasm to clean it from graft-transmissible pathogens followed by pathogen testing (indexing) to make sure the pathogens are not present.

Quarantine may be achieved by planting in isolated locations, use of physical barriers such as quarantine greenhouses, and, with citrus, byuse of in vitro quarantine by placing bud sticks in media in glass tubes and forcing small shoots for shoot-trip grafting (Navarro, 1993). The newly acquired germplasm is first indexed for presence of graft-transmissible pathogens and then therapied by shoot-tip grafting and/or thermotherapy to free the germplasm from the identified pathogen(s). The therapied germplasm is then re-indexed to assure freedom from the known graft-transmissible pathogens (Roistacher, 1991).

In the past, seed was often imported without concern of introducing graft-transmissible pathogens. This is no longer a good practice. In citrus, there are now reports of several graft-transmissible pathogens which are seed borne: CVC (Li et al., 2003), witches' broom disease of lime (WBDL) (El-Kharbotly et al., 2003; Khan et al., 2002), as well as psorosis-like pathogens in P. trifoliata and in hybrids having P. trifoliata as one of the parents (R. Lee, unpublished; Roistacher, 1991; Powell et al., 1998). In other perennial crops, many potyviruses are seed transmitted (Brunt et al., 1996). Care needs to be taken to test for pathogens which are known to be seed transmitted, especially when importing exotic seed.

Clean Stock Programs

There is a need to recover healthy plants from locally grown varieties and cultivars. The clean stock program provides for identification of superior performing or horticulturally desirable trees from domestic sources without regard for their phytosanitation condition, followed by pathogen testing and therapy to produce sources of pathogen-tested (healthy) germplasm. Documentable criteria, such as consistent high yield, measurable fruit quality and color, etc., are often used to ensure that resources spent for cleanup of domestic material will result in a tangible benefit over varieties/clones that are already available. Often local varieties are best adapted to the local climate, soil, and markets, but sometimes the full potential is not being realized because they are infected with graft-transmissible pathogens.

Several steps are involved in the establishment of a clean stock program: selection of mother trees from local cultivars, indexing of the selected mother trees, recovery of pathogen-free plants by *in vitro* shoot tip grafting and/or thermal therapy, indexing of the plants recovered, horticultural evaluation of the pathogen-tested plants, and maintenance of pathogen tested (healthy) plants under protected conditions. Graft-transmissible pathogens found in the domestic trees should be retained in a virus collection (virus bank), as they are useful as positive controls for future biological/laboratory indexing.

Healthy plants are recovered from selected mother trees. This most commonly is done by shoot-tip grafting procedures, but thermotherapy and in vivo or in vitro nucellar embryony methods are also used (Koizumi, 1998; Roistacher, 1977; D'Onghia et al., 2001). Shoot-tip grafting and thermotherapy methods result in plants which do not express juvenility. Nucellar embryony also is effective for elimination of graft-transmissible pathogens because most pathogens are not seed transmissible. However, nucellar plants express juvenile characteristics such as thorniness, late bearing, upright growth, and excessive tree vigor. Additionally, not all seedlings are true to type.

Horticultural evaluation of the recovered plants is an important component of a clean stock program (Roistacher et al., 1977). There are no reports of shoot-tip-grafted plants expressing abnormal traits, but there can always be a spontaneous bud sprouts or mislabeling may occur. Additionally the horticultural evaluation provides useful production information over a period of time, enabling growers to choose the most productive clonal selections.

Once germplasm is recovered as pathogen-tested, healthy plants, care must be given to make sure it does not become re-infected by graft-transmissible pathogens, especially the pathogens having insect vectors (Table 1). Healthy plants must be maintained either in a screenhouse or a greenhouse with appropriate measures so that they are protected from vectors. Plants in the clean stock program need to be re-indexed on a regular, recurring basis for the graft-transmissible pathogens which are present (Roistacher et al., 1977; Lee et al., 1999).

Certification Programs

The purpose of certification programs is to guarantee the sanitary status and trueness to type of the nursery material during the process of propagation and distribution to growers (Lee et al., 1999). The healthy material utilized by the certification program is derived from the quarantine and clean stock programs. Certification programs sometime call for minimum horticultural standards before trees may be moved from a nursery, for example, a minimum stem diameter and/or a pre-determined height of the budunion. The first citrus certification program was started in California after a proposal by Hiltabrand (1957) for control of psorosis. Other certification programs were established in Florida, Spain, South Africa, Taiwan, and Australia, and more recently in Belize, Jamaica, Brazil (Sao Paulo State), Uruguay, Argentina, and Oman.

Certification programs which ensure that healthy plants are planted by the industry provide the platform for an integrated pest management approach for growing citrus

(Navarro 1986; Lee and Rocha-Pena, 1992). If a new graft-transmissible pathogen should occur, the certification program, because of the required indexing to ensure the pathogen-tested status of the germplasm, ensures that the new pathogens can readily be identified and may assure that they do not get widely distributed throughout the growing area. Record keeping is an important part of a certification program. This allows for tracing problems, which might appear at a later time, back to a budwood source tree and/or specific nursery. The certification program provides the mechanism for the release of new varieties and cultivars, for gathering yield and horticulture information, and for the distribution of extension-type information.

The Benefits of Planting Healthy Trees: A Case Study

Control of Nematodes by Use of a Nursery Nematode Certification Program in Florida

In the early 1950s, a slowly spreading chronic-decline disease of unknown etiology appeared in central Florida. Affected trees did not die but were non-productive. It was discovered that the cause of this “spreading decline” was a nematode, Radopholus similis, commonly called the citrus-burrowing nematode (Lee et al., 1999; Fegan et al., 2004). In 1954, surveys indicated that about 5,400 acres were infested, and it was estimated that if no measures were take, about 53,000 acres would be infested by 1967. A Florida nursery nematode certification program was developed and implemented in 1958. The program included surveys to identify infested areas, an eradication program whereby infested trees were burned; infested areas being fumigated and kept fallow before replanting; a program to establish chemical barriers to keep roots from infested areas from encroaching into non-infested areas; and a certification program whereby all nursery sites (not just citrus nurseries), soil pits, or borrow pits had to be certified as free of the burrowing nematode. The eradication and barrier programs were mandatory at first, and over time became voluntary. The chemical barrier program was eventually discontinued due to environmental concerns, but some barriers are still maintained by mechanical root pruning and use of nematode-resistant rootstocks. As time progressed, the citrus nematode, Tylenchulus semipenetrans, was added as a regulated nematode, and later the coffee nematode, Pratylenchus coffeae, was located and added to the program.

The Florida nursery nematode certification program has been tremendously successful (Lee et al., 1999). In 1953, 278 citrus nurseries were infested with the burrowing nematode; after the program was implemented the number declined rapidly. The burrowing nematode has not been found in a nursery since 1970. Only about 9,000 acres of citrus land was infested by the burrowing nematode in 1984. Because of severe freezes occurring in 1963, and again in 1983, 1985, and 1989, much of the land used for citrus production in central Florida has been abandoned for citrus and replaced by new acreage in the southern part of the state where it is warmer. All of this new land planted to citrus has remained free of nematodes because of the nematode certification program. There is less need for chemical control or for nematode control. Rootstocks having resistance to nematodes are less likely to have the source of resistance break down, as they are not being constantly challenged by the nematodes.

In a cost-benefit analysis of the burrowing nematode control program from 1960-1994 by Lee et al. (1999), it was estimated that there was a return of $1 million for every $70,000 invested in the program. This estimate was derived by considering only the yield losses due to the burrowing nematode and the citrus acreage that would have been infested with the burrowing nematode if the nematode certification program had not been in place. For the year 1994-1995, the benefit of the nematode certification program, considering both the citrus nematode and the burrowing nematode, was estimated to be $16.7 million; with 44,500 acres free of the burrowing nematode and 75% of the total citrus area now free of the citrus nematode. A 5% loss of yield was calculated for the citrus nematode and a 25% yield loss for the burrowing nematode. Thus for every $1,403 dollars invested in the nematode certification program for 1994-1995, there was a return to the industry of $1 million.

HLB: Management Strategies and Economic Impact

There are a number of emerging graft-transmissible pathogens which pose serious threats to the sustainability of citrus in North America. Table 1 summarizes these graft-transmissible pathogens of citrus which have insect vectors or other means of spread. We will consider HLB, commonly called citrus greening, as a case study to determine the potential effect this disease could have on citrus and to outline the options available for its control/management.

HLB is caused by a fastidious phloem-inhabiting bacterium, Candidatus Liberobacter (Bove, 1995; Bove and Garnier, 1984; Bove, 2006). Presently there are three recognized strains of HLB: the Asian form, Candidatus L. asiaticus, which expressed the most severe symptoms under warm conditions; the African form, Candidatus L. africanus, which expressed the most severe symptoms under cooler conditions; and the Brazilian form, Candidatus L. americanus which was first found in 2004. Phloem-feeding psyllids are the vectors of HLB. Diaphorina citri and Trioza erytreae are the psyllid vectors associated with the Asian form and African form of HLB, respectively; however, either vector may transmit either form of HLB. D. citri vectors both C. L. asiaticus and C. L. americanus in Brazil. D. citri has become widely distributed throughout most of the citrus areas of the Americas (with the exception of California); thus if the HLB pathogen is introduced into most citrus areas of the New World, the vector is already present. HLB has been reported from 29 countries in Asia and Africa and has caused severe economic losses in many areas (Bove, 2006). In the areas where HLB occurs, the disease is considered to be the most limiting factor of citrus production.

Diagnosis of the disease is usually done now by PCR assay from symptomatic tissue, but use of transmission electron microscopy also has been used (Bove, 2006). Use of biological indexing for diagnosis requires several months and consideration must be given to the temperatures under which the different species express symptoms; additionally, symptoms may be masked by the presence of other graft-transmissible pathogens, such as severe strains of CTV (DaGraca and Korsten, 2004). It becomes easy to declare a positive when symptoms occur, but due to the latency period from time of inoculation and appearance of symptoms, it becomes difficult to declare a test negative for HLB with confidence. Real-time PCR assays have been developed (Li et al., 2006; Irey et al., 2006) for quantitative detection of HLB from plant tissue and more recently, from the psyllid vectors (Manjunath et al., 2006). PCR detection for HLB is limited to the 16S rDNA gene and other highly conserved regions of bacterial genomes as the HLB bacterium has not yet been cultured (Bove, 2006). There is a critical need for further genomic characterization of the HLB bacterium for the development of more robust diagnostic methods.

The best control measure for HLB is exclusion, thus the quarantine component of citrus certification programs is extremely important. In countries where HLB and its vectors are endemic, realizing an economic return from citrus requires planting HLB-free trees initially, regular monitoring of vector populations and applying chemical control for vectors when critical threshold values are met, and the removal of inoculum sources (Bove, 2006; DaGraca and Korsten, 2004; Roistacher, 1996). Removal of inoculum is usually based on pre-determined criteria. For example, in Brazil entire blocks are eradicated when 20% of the trees are showing HLB symptoms (Ruiz, et al., 2006). In South Africa, where the African strain of HLB occurs, pruning of symptomatic branches from field trees on a regular schedule helps remove inoculum (Roistacher, 1997; Buitendag and von Broembsen, 1993; LeRoux, 2006). Symptoms of other chronic decline diseases of citrus, such as CTV, citrus blight, and stubborn, can make the identification of HLB-infected trees difficult. At the present time, HLB represents a serious threat to all of the citrus regions in the Americas.

The economic cost of living with HLB are great. Grenzebach (1994) reported on an economic study of tangerine production in Thailand. He used cost data provided by the Thailand Department of Agriculture Extension and by the Ministry of Agricultural Publications, and a average national production of 12.5 T/ha. The management practices as outlined above were not being used in Thailand. An average rate of spread of HLB was estimated to be 10% per year and replanting of non-productive trees was done continually. An average tangerine grove would produce 22.75 T/ha in years 5 through 8, then decline to 6.5 T/ha by year 12 for an average life cycle of 12 years for an average tangerine grove. Roistacher (1996) further refined the economic study of citrus production in Thailand, considering the rate of spread rates of HLB in different regions of the country and the disease status of the plants being used to establish groves. Roistacher's model indicated that if healthy trees were used to establish the grove, and considering the lack of management of the psyllid vectors and reduction of HLB inoculum, a grove may be expected to last for 10 years and have a cumulative profit of US$3,383/ha. However, if proper management of the psyllid vectors and reduction of HLB inoculum were followed, it may be possible to extend the life cycle of the block to 20 years for a cumulative profit of US$125,000/ha.

Summary

With all perennial fruit crops, there is a constant demand for new varieties which will appeal more to the consumers and/or offer horticultural/disease(s) advantages. A safe method for accessing and making this exotic germplasm available to the industry is essential. The exclusion of exotic graft-transmissible pathogens and other pests and the prevention of further spread of existing pests already established in the area may be accomplished by the use of mandatory certification programs. Such certification programs must incorporate a quarantine component to prevent the introduction of exotic pests, a clean stock program to allow for the therapy of locally available germplasm and its maintenance as pathogen-tested germplasm, and a certification program to allow for the delivery of the horticulturally select pathogen-tested plants to the local growers and farmers.

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Table 1. Emerging graft-transmissible pathogens of citrus having vector or other means of natural spread.

Graft-transmissible disease	Causal agent	Vector or means of spread
Citrus blight[a]	unknown	Unknown
Citrus chlorotic dwarf[b]	unknown virus-like agent	*Parabemisia myricae* Kuwana, whitefly
Citrus-variegated chlorosis[c]	strain of *Xylella fastidiosa* Wells	Several species of sharpshooters (Hemiptera: Cicadellidae)
Huanglongbing (citrus greening)[d]	*Candidates* Liberobacter asiaticum; *C.* L. africanum; *C.* L. Americanus (Asian, African, and Brazilian greening, respectively)	*Diaphorina citri* Kuwayama, *Trioza erytreae* Del Guercio
Indian citrus mosaic[e]	Indian citrus mosaic badnavirus	*Planococcus citri* Risso, the citrus mealy bug
leprosis[f]	Citrus leprosis rhabdovirus	*Brevipalpus spp.* mites (Acari : Tenuipalpidae)
Naturally spread psorosis[a]	Citrus psorosis virus	Unknown
Satsuma dwarf[g]	Satsuma dwarf nepovirus	Unidentified soilborne agent
Stubborn[h]	*Spiroplasma citri* Saglio	Leafhoppers: *Scaphytopius nitrides* Baker, *Neoaliturus tenellus* Gillette and Baker, *N. haemoceps* Muls. & Reyl.
Tristeza[i]	Citrus tristeza closterovirus	Several aphid species, *Toxoptera citricida* Kirkaldy, *Aphis gossypii* Glover, and *Aphis citricola* van der Goot are the most common
Witches' broom[j]	*Candidates* Phytoplasma aurantifolia	*Hishimonus phycitis* Distant suspected, not confirmed
Woody gall[g]	Citrus vein enation virus (Luteovirus-like)	Aphids, *T. citricida* and *A. gossypii*

[a] Derrick and Timmer, 2000
[b] Kersting et al., 1996
[c] Rosetti, 2000
[d] Bove, 2006
[e] Ahlawat et al., 1996
[f] Rodrigues et al., 2003
[g] Whiteside et al., 1988
[h] Bove, 1995
[i] Lee and Rocha Pena, 1992
[j] El-Kharbotly et al., 2000

BIOPESTICIDES: ADOPTION AND SUCCESS IN IPM PROGRAMS

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Abstract
Biopesticides are reduced-risk products based on biological or naturally derived chemistry. Biopesticides can have an important role for management of insects and diseases, and are now important components of IPM programs worldwide. IPM typically emphasizes growth of a healthy crop, and use of biological alternatives has a significant role in promoting attributes beyond pest management. Additional benefits include resistance management through alternate modes of action, residue management, and utility in organic production. Biopesticides can also be integrated into existing agricultural production systems, using conventional pesticides as a means to reduce human health and environmental risks associated with pesticide use. This talk will review the barriers to adoption of new biological alternatives for pest management and will highlight success stories that will specifically demonstrate areas where they have proved to be economic and environmentally friendly alternatives for management of pests and diseases.

Key words: biopesticides, IPM, resistance management, residue management

BARN OWLS AS A SUSTAINABLE MEANS OF RODENT CONTROL

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Abstract

Rodent pests cause millions of dollars in damages annually to sugarcane and vegetables in the Everglades agricultural area of south Florida. Growers have traditionally relied on chemical rodenticides to control these rodent pests. However, chemical control can be expensive and may pose an environmental threat to water supplies and non-target wildlife. The barn owl (*Tyto alba*) is native to Florida and is widely recognized as one of nature's most effective rodent predators. Conservative estimates put the number of rodents eliminated by a nesting pair of barn owls at more than 1,500 per year. However, due to a paucity of suitable nesting sites, *T. alba's* numbers in the Everglades agricultural area are well below optimal. A nesting box program to enhance barn owl populations in south Florida was initiated during the 1990s and has proven quite successful in providing barn owl nesting and roosting sites. Mounted on tall poles, the nesting boxes are located along field perimeters and ditch banks and are rapidly colonized, many within days of placement. The nesting box program has gained acceptance by all aspects of agriculture in the area and, based on anecdotal evidence, some growers have even discontinued the use of chemical rodenticides.

Key words: barn owl, sustainable rodent control, tyto alba, nesting boxes, Florida, IPM

BARRIERS TO WIDESPREAD CONVERSION FROM CHEMICAL PEST CONTROL TO NON-CHEMICAL METHODS IN U.S. AGRICULTURE

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Abstract

Herbicides and fungicides are widely used to kill weeds and plant pathogens in agricultural crops. CropLife Foundation assessed the value of herbicides and fungicides to U.S. farmers by evaluating crop losses to weeds and diseases and quantifying the cost and effectiveness of chemical and alternative control methods. These studies clearly identify barriers to the adoption of non-chemical methods of pest control as potential replacements for synthetic chemical pesticides. Non-chemical weed control relies primarily on tillage and hand weeding, practices which are labor intensive and expensive. Lack of available labor and high wage rates prohibit use of these techniques for production agriculture. Further, expense involved in non-chemical weed control is a significant constraint to expansion of organic agriculture in the U.S. Genetic resistance to pathogens can be an effective non-chemical disease management tool, but it cannot replace fungicides. Incorporation of disease-resistant genes into desirable varieties is difficult, and genetic resistance commonly breaks down. Under such conditions, fungicides are the only responsive and reliable disease-control method. The comparative ineffectiveness of non-chemical pest-control methods, along with their expense and instability, makes synthetic chemical pesticides the only sustainable means of agricultural weed and disease control.

Key words: crop losses, economics, fungicide, herbicides, pest management

Introduction

Herbicides and fungicides are widely used to kill weeds and plant pathogens in agricultural crops. CropLife Foundation (CLF) has released two studies that quantify the potential impacts on crop production costs and crop yields, if growers did not use fungicides and herbicides and relied on the best available alternatives. Farmers choose to use fungicides and herbicides because they are more effective and lower in cost than alternatives to prevent crop losses. Replacement of fungicides and herbicides on a large commercial scale is unlikely for the foreseeable future due to their effectiveness and low cost.

Fungicide Use

Fungicides are used on more than 90% of most fruit and vegetable crops every year. CLF study identified 231 diseases of 50 crops controlled with use of fungicide spraying. Most crops are subject to five or more diseases controlled by fungicide spraying.

Fungicides have been used for a long time in the U.S., starting with sulfur, copper, and Bordeaux mixtures in the late 1800s. In the early 1900s, powdery mildew was considered capable of destroying the entire grape crop in California if sulfur sprays were not made. By the 1920s, spraying fungicides (lime sulfur) became a universal practice in U.S. apple orchards, and it was considered to be impossible to grow apples for market without fungicide sprays.

Fungicides provide a high level of control of pathogens with properly timed sprays reducing the population of pathogens by 90% or more. Recent fungicide tests show large reductions in disease development with associated increases in yield: watermelon yields up 61% as a result of gummy stem blight control; citrus scab incidence reduced from 44% to 4%; purple spot losses in asparagus reduced 99%; mummyberrry incidence in blueberries reduced 98-99%; black rot of grapes reduced from 95% to 1%.

The primary non-fungicidal plant disease-control method that has been researched for decades is host-plant resistance, which has proven to be a durable method of disease control for several major field crops—corn, sorghum, and sugarcane. These are crops for which appearance characteristics are less important than yield and disease-resistance characteristics. The success of host-plant resistance for these crops has depended on an ongoing commitment to plant breeding since pathogen populations can evolve and overcome the resistance. As a result, in order to sustain host-plant resistance, crop breeding needs to be continuous with new resistant varieties in development at all times.

For some crops, despite decades of breeding thousands of new varieties, disease suppression with host-plant resistance has proven completely unstable because the pathogen mutates so rapidly. For example, no potato variety has been produced combining resistance genes to all late-blight races with the many genetic traits needed to produce a commercial variety. Although the search for peanut cultivars resistant to white mold originated in 1917 is ongoing, a high degree of resistance has not been found.

In many cases, resistant cultivars have been released but are not widely planted because of poor horticultural characteristics. For example, more than 20 apple cultivars bred with resistance to apple scab have been released, but none are widely-planted since they produce fruit of small size, have a tendency to ripen unevenly, and have brownish interiors. Usually, there is a tradeoff between host-plant resistance and other desirable traits that are lost in the breeding process. The tradeoff in sugarbeets is lower yield with increased cercospora resistance.

Often "resistant" cultivars are not totally resistant to the pathogen. For example, resistant peanut cultivars provide 20-40% control of leaf spot, rust, and stem rot. By contrast, fungicides provide more than 90% control. The pepper cultivar Palladin possesses excellent horticultural characteristics and exhibits excellent resistance to the crown-rot phase of phytophthora; however, it does not possess resistance to the foliar phase of phytophthora blight which requires regular fungicide applications for control.

Some examples of the breakdown in host-plant resistance which have resulted in a need to spray fungicides to control pathogens illustrate how tenuous the non-fungicidal strategy can be:

- Wheat cultivars with leaf-rust-resistance genes have been available since the 1940s. Within a few years of release, virulent leaf rust strains appear that render the varietal resistance ineffective. Most recently, resistance broke down in previously resistant cultivars in the northwest. The loss in wheat yield would have been 20% without the use of fungicides.
- Prior to 1960, downy mildew was a significant disease on lettuce in California. It was brought under control with resistance from wild lettuce. New races of the fungus appeared in 1976 and overcame the resistance. In 1989, another set of resistant cultivars were introduced, but by 1992 control slipped again and fungicides have been used ever since to manage the disease.

The importance of fungicides to fruit and vegetable production is also supported by their use by organic growers who are permitted the use of copper, lime sulfur, and sulfur, Organic grape and strawberry growers in California typically apply 66 and 45 pounds of sulfur per acre, respectively, to control powdery mildew. Organic apple growers in the

Northeast typically spray 10 gallons of lime sulfur and 12 pounds of wettable sulfur per acre for disease control.

Without use of fungicides, yields of most fruit and vegetable crops would decline by 30-70%. There are no alternatives that would control the broad spectrum of diseases that develop in most crops. Alternative controls also are typically less effective than the use of chemical fungicides. Growers will continue to use the most effective controls. The CLF study on the value of fungicides determined that growers gain $15 for every dollar spent on fungicides and their application.

Herbicide Use

Widespread herbicide use is a relatively recent development in U.S. agriculture in comparison to fungicide use. Use of chemical sprays to kill weeds began in the 1950s, resulting in rapid adoption on most crop acres. Herbicides are used on 215 million crop acres in the U.S. Herbicides largely replaced the practice of hand-weeding crops and greatly reduced the use of cultivation of fields with tractors.

Farmers have come to demand high performance from herbicides. They expect that 95-99% of the population of all the key weed species in a field (usually five or six) be killed with one or two sprays and that season-long control is maintained with no crop injury.

The problem of controlling weeds without herbicides has been cited numerous times as the single biggest obstacle that organic growers encounter. Out of 30 research areas, organic farmers ranked weed control as the number one priority in three national surveys. Organic growers rely extensively on cultivation and hand weeding to control weed populations. Hand weeding in organic crops ranges from two to 165 hours per acre, along with two to nine tillage operations. Poor weed control is often cited as a major reason for lower yields in organic production. Labor for hand weeding is expensive and scarce. Growers budget $10/hour for hand weeding which includes wages, supervision, transportation, and facilities. Because of the expense of labor and the large need for hand weeding, organic growers can spend up to $1,000/A in labor for weeding in comparison to growers who use herbicides for $50/A.

Studies have shown that crop yields need not decline without herbicides, if enough labor is used to pull weeds: corn (60 hours/A), cotton (67 hours/A), spinach (209 hours/A).

One writer concluded that to hand weed the nation's corn acres without yield loss would require a labor force of 18 million people. The CLF study estimated that 70 million workers would be required to hand weed crops in the U.S. with no loss in yield. Most simulation studies that estimate the value of herbicides forecast an increase in hand weeding that is inadequate to prevent yield loss. The American Farm Bureau estimated California lettuce yields would decline by 13% without herbicides, despite the substitution of two cultivations and 38 hours of labor. Similarly Texas onion yields were estimated to decline by 25%, despite an additional cultivation and 32 hours of labor.

In recent years, several national studies have concluded that the nonuse of herbicides would lead to significantly lower crop yields due to the substitution of less-efficacious control alternatives (hand weeding and cultivation). USDA reports on strawberries, carrots, cotton, and processed tomatoes concluded that national production would decline by 30%, 48%, 27%, and 20% respectively without use of herbicides. The Weed Science Society of America (WSSA) published estimates by state for 46 crops that estimated yield changes likely to occur without herbicide use and the substitution of alternative best management practices.

The CLF study on herbicides organized the predicted yield loss estimates from recent USDA, WSSA, and Farm Bureau studies into a comprehensive aggregate study estimating likely impacts on crop yields and production costs if herbicides were not used. The CLF study predicts a decline in overall U.S. crop production of 20% without herbicides, despite the utilization of an additional 1.1 billion hours of hand weeding (7 million workers) and an increase of 838 million acre-trips with cultivators. The need for fuel would be 337 million gallons higher, since twice as many cultivation trips would be needed to replace herbicide sprays. Cultivators use four times more fuel per trip than herbicide sprayers do.

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STRATEGIES IN THE UNIVERSITY OF CALIFORNIA TO REDUCE THE ENVIRONMENTAL FOOTPRINT OF PEST MANAGEMENT

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Abstract

Integrated pest management has been under development in California for more than 50 years now. Very reliable systems are in place for the management of the great majority of pests, including insects, mites, weeds, and pathogens, although invasive exotic pests accidentally introduced to the state are a continuing threat. More generally, the challenges facing pest management today in California are to reduce the environmental impact s of pest management. Although much of the focus of public concern about pest management is on pesticides, the use of tactics like tillage and burning for weed management are also serious issues, due to the high levels of respirable dust in the central valley. Indeed, reduction in tillage is likely to be driven by many factors, including fuel costs, but will in turn probably change pest management issues in the crops. Other issues being addressed in the UC include volatile organic compounds from pesticide applications, which contribute to ozone, pesticide drift in the air, and pesticides in water bodies. The University of California spends some $60 million per year on research and another $20 million per year on extension in pest management. A continuing challenge is to focus that investment on higher priority issues.

Key words: volatile organic compounds, water quality, air quality, organic agriculture, pesticides

ASSESSING THE POTENTIAL VIABILITY OF PHEROMONE-BASED, AGROECOLOGICAL APPROACHES TO PEST MANAGEMENT IN WALNUTS

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Abstract
In order to control codling moth and walnut husk fly, walnut growers use many organophosphate and/or pyrethroid insecticides that have been potentially linked to secondary pest outbreaks of aphid and mite. Although there are alternatives, low-risk pest controls such as pheromone mating disruption are available, but the common perception is that they are too expensive. The purpose of this project was to determine the percentage of growers that would find an alternative strategy less expensive based on secondary pest costs and pheromone active-ingredient level. The study found that an average of 12-57% (San Joaquin) and 11-34% (Tehama) of growers preferred an alternative strategy based on cost comparison to current practices. The large variation in percentage was correlated with whether high or low levels of active ingredient and secondary pest costs were evaluated. These results show promise that under ideal conditions, alternative pest control strategies may be of equivalent or less expense than conventional methods for a significant percentage of growers.

Key words: alternative pest control methods, secondary costs, walnut growers

Introduction

California is responsible for 99% of all walnuts produced in the United States. The estimated crop value of 2004 was $439 million (California Walnut Industry, 2006). Codling moth (*Cydia pomonella*) and walnut husk fly (*Rhagoletis completa*) are considered by many to be the most problematic pests facing growers today, creating significant economic loss if not treated (Ramos, 1998; UC-IPM, 2006). To control these pests, growers currently employ organophosphate and pyrethroid insecticides listed in the Food Quality Protection Act (FQPA) raw and processed food schedule for pesticide-tolerance reassessment (EPA, 1997). Scientific research has shown that the broad spectrum nature of these insecticides can target beneficial insects as well as the intended pests, which can result in secondary pest outbreaks of aphids and mites, and the additional use of FQPA-targeted acaricides (Agnello et al., 2003; EPA, 1997; Prischmann et al., 2005; Zalom et al., 2001). In the face of potential restrictions and regulations, it is important to find pest control solutions that are characterized by high efficacy, low cost, and low-risk, resulting in a situation beneficial for growers, consumers, and the environment.

The market has responded to environmental awareness and impending regulation through new technology in the form of pheromone mating disruption (Checkmate®, 3M®), insect growth regulators such as tebufenozide (Confirm®) and methoxyfenozide (Intrepid), and microbial controls such as spinosad (GF-120®, Success®, Entrust®) and baccilus thuringiensis (Dipel®), to list a few. Although varying in their methods of control, these new alternatives present significantly less threat to beneficial predator insects and are often lower in toxicity to wildlife, water, and human health. Many of these alternative controls are more expensive, however, due to increased number of applications per season, higher material costs, and a lower number of target pests controlled per application. In addition, the perception of efficacy of these controls has been variable, with growers' in-field experiences not always reflecting positive outcomes seen in scientific research studies.

The project was based on the hypothesis that a grower able to attain effective pest control under an agroecological approach, defined as pest management strategies incorporating narrow spectrum, low-risk controls and ecological engineering, could potentially find that overall pest management costs are not that different from the costs of a conventional approach using popular broad spectrum insecticides. The theory behind the hypothesis was that the higher material costs of the alternative products could be offset by a decrease in costs of secondary pest outbreaks of mites and aphids as beneficial predators are able to re-establish. In order to explore this hypothesis, the study chose to analyze the agroecological approach under a long-range, ideal scenario in which ecological engineering has been successfully combined with alternative products to achieve similar efficacy to the conventional approach and reduction or elimination of secondary pest costs. It was not the intention of the project to undervalue the importance of transitional costs such as the potential emergence of new pests that were previously controlled or the expenses encountered during the learning-curve period, but to instead create a snapshot view of how many growers would find effective agroecological approaches to be economically viable alternatives, and how much the preference level depended on the strength of biological control or the active ingredient level of product. An important objective of this project was to offer an outline of various strategies and different potential economic outcomes, so that walnut stakeholders such as growers and policy makers can measure the costs and benefits as they apply to their own individual circumstances.

Materials and Methods

In order to compare the cost of the two approaches, various pest management strategies must be defined. For the purposes of this study, a pest management strategy consists of the specific product mixes and use rates throughout the season for controlling insect and mite pests. The strategy can then be categorized under a broader chemical class such as organophosphate ("OP"), pyrethroid ("Pyrethroid"), or a combination of the two ("Combination"), based on the product choices of the grower.

Pest management strategies under the conventional approach were determined through actual grower data reported to the Pesticide Use Report (PUR), a public database of legally mandated California pesticide application reports managed by the California Department of Pesticide Regulation. The PUR database offers a wealth of information about grower product choice, chemical active ingredient (a.i.), use rates (amount per acre treated), use intensity (amount per acre planted), and number of applications per season, creating a detailed picture of each grower's pest management strategy used throughout the year (CDPR, 2004).

The study analyzed conventional strategies employed by growers in San Joaquin and Tehama counties for the years 2002 through 2004. In 2003, San Joaquin had 29,457 bearing acres of walnuts, while Tehama had a smaller amount of production at 12,721 bearing acres (USDA, 2004). Only data for growers with probable codling moth problems and bearing acreage were analyzed. San Joaquin County sample size ranged from 200 to 242 growers over the three years, while Tehama had only 30 to 41 representative growers.

Pest management strategies representing the agroecological approach (Figure 1) were centered on pheromone mating disruption as the predominant codling moth control, given the pest's economic importance and the promise of mating disruption as an effective treatment (Balint, 2002; 2003; 2004). To account for growers with high codling moth pressure, an optional application of the insect growth regulator tebufenozide (Confirm®) was analyzed

(Balint, 2004). Spinosad (Success®), a microbial walnut husk fly control which has been reported to possibly also control hyperparasitoids of aphid, was included for growers whose PUR data indicated a walnut husk fly problem (Mills et al., 2004). A strategy employing malathion, an organophosphate receiving a "slightly toxic" rating from the EPA, was also analyzed as a potential transitional method for growers with very high pest pressure (MeisterPro, 2006).

The costs of the various pest management strategies were calculated through combining the use rate (amount/acre) and number of applications with product prices for 2003 ($/amount, Table 1), and a standardized application cost, covering fuel, labor, and maintenance (De Moura, 2005). Most pest controls were considered to be applied by a typical orchard sprayer with a standardized application cost of $15.57/application/acre (Buchner et al., 2002). Spinosad applications can be applied using an ATV sprayer at $.75/application/acre (Van Steenwyk, 2006). Multiple pesticides reported by a grower on the same date and same acreage were considered to be combined in the sprayer together, a practice commonly followed by growers to reduce total sprayer application costs. Similarly, for the estimated agroecological strategy with pheromone and malathion, one of the four pheromone applications was considered to also contain an application of malathion within the sprayer, thus reducing costs. All pest expenses, including insecticide, miticide, alternative control, and application costs throughout the season, were summed to arrive at a total pest management strategy cost per acre for each grower. These costs were then averaged under each chemical class to gain insight into the variation in expense among conventional methods. Means were compared using Tukey's studentized range test on SAS® 9.1 software to account for the unequal sample sizes (SAS, 2006). Agroecological pest management costs were estimated based on each grower's specific pests as analyzed from the PUR database.

The project developed the following "economic preference" criterion: if a grower's total current costs were within $5/acre or less than the estimated alternative strategy cost, then that grower was considered to "prefer" the alternative strategy on an economic level.

The alternative approaches were evaluated based on their sensitivity to efficacy as represented by pheromone active ingredient level, as well as to secondary pest costs, signifying biological control effectiveness. The sensitivity analysis to active ingredient evaluated pheromone at both five and 10 grams of active ingredient. For biological control effectiveness, three levels of secondary pest costs were analyzed: elimination of costs, halved costs, and no change in cost, reflecting strong, moderate, and weak biological control efficacy, respectively. In this study, secondary pest costs were represented by total cost of all miticides used throughout the season by a grower.

Results and Discussion

Cost Analysis

Table 2 shows that growers following a combination chemical class had the highest cost at $195/acre, followed by organophosphate at $137/acre, with pyrethroid being the least expensive at $85/acre. Statistically, there was not always a clear delineation between the costs of different approaches, due to small sample sizes of certain chemical classes and high variation in price and application amount of products (Table 2).

Percentages of growers using acaricides throughout the season ranged from 56% to 85% (Table 3) in San Joaquin, and 52% to 90% in Tehama, reflecting the presence of secondary pest outbreaks. It is possible that growers could apply an acaricide automatically with a broad spectrum pesticide as a preventative measure, predicting an outbreak and preferring to save time and costs by applying all at once. However, although this second scenario may not offer a direct link between broad spectrum controls and secondary pest outbreaks, it still defines a strong link to secondary pest costs.

For those growers who treated for mites, acaricide material costs represented from 43% to 76% of their total insecticide material costs in San Joaquin, and from 33% to 82% in Tehama. Therefore, if narrow-spectrum controls could allow beneficial insects to reduce secondary pest outbreaks, the increase in cost for alternative controls could be offset by an average of half of total current costs (Table 3).

Alternative strategy cost preference

Table 4 shows that on average, 20-38% of Tehama growers and 28-64% of San Joaquin growers would economically prefer an alternative approach employing Success, while 16-39% of Tehama growers and 19-52% of San Joaquin growers would prefer the transitional malathion approach to their current methods. Table 4, secondary pest costs were eliminated under the narrow-spectrum Success option, whereas they were reduced by half for the malathion option, given the low use rate of the broad-spectrum organophosphate.

Given the wide range of percentage distribution, the project conducted an analysis to further define the importance of secondary pest cost, pheromone active ingredient level, and chemical class choice in determining economic preference. Table 5 shows the results of a sensitivity analysis to change in pheromone active ingredient from 10 grams to five grams, and to reduction of a growers current secondary pest costs by half or in full. If pheromone active ingredient could be reduced from 10 grams to five grams and still achieve efficacy, the percentage of growers economically preferring the strategy would increase by 10-14% in Tehama and 16-24% in San Joaquin. If an agroecological approach could reduce secondary pest costs by half, the percentage of growers economically preferring the strategy would increase by an average of 6-9% in Tehama and 10-15% in San Joaquin. If secondary pest costs could be completely eliminated, economic preference would increase by 12-14% in Tehama and 21-29% in San Joaquin (Table 5).

To further characterize the growers who would economically prefer an agroecological strategy to their current practices, the analysis was evaluated under each chemical class. Reflecting average pest management costs, Table 6 shows that the most expensive chemical class of “combination” had the highest percentage of growers that would find the cost of an estimated agroecological strategy less than what they are currently paying. The “OP” chemical class had the second highest percentage, followed by the “pyrethroid” class. Percentages decreased as estimated agroecological strategies increased in cost, due to increases in active ingredient or secondary pest costs. Although this table may be unsurprising given the simplicity of the economic criterion based on cost comparison, the table is included to serve as a tool for stakeholders to identify current characteristics of those growers most likely to economically favor an agroecological approach.

In conclusion, results of this study suggest that agroecological controls currently available for walnut growers may hold promise economically. The sensitivity analyses show that the “economic preference” of an agroecological approach by growers is of similar sensitivity to both active ingredient of pheromone and secondary pest cost level: Tehama showed a 10-14% change in preference based on active ingredient and 12-14% preference change based on secondary pest costs, while San Joaquin had a 16-24% change in preference based on active ingredient and 21-29% preference change based on secondary pest costs. Further research is therefore needed to understand the population dynamics of beneficial insects and secondary pests in relation to orchard characteristics, as well as the proper active ingredient and formula of pheromone and other narrow spectrum, low-risk products to achieve the highest efficacy. Although many unknowns still remain, this analysis offers a hopeful prediction that agroecological, narrow-spectrum strategies can be both economically as well as environmentally viable, creating a beneficial situation for all stakeholders. As research continues, walnut production shows strong potential to be able increase sustainability and lower risk in the long run.

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Table 1. Prices (2003) and rates of estimated alternative strategy products (Balint, 2004, Buchner et al, 2002, DeMoura, 2005).

Control	**Price ($)**	**Rate**
Suttera CM-f sprayable pheromone	$2.00/gram	5 or 10 g a.i./acre
Confirm (Tebufenozide)	$22/pint	1 pint/acre
Success (Spinosad)	$105.75/pint	1 oz/acre
Malathion 8	$40/gal	.5 gal/acre
NuLure (bait)	$23.89/gal	.375 gal/acre
NuFilm (spreader/sticker)	$1.92/pint	6 oz/acre
Orchard sprayer application	$15.57/acre	
ATV sprayer for Spinosad	$.75/acre	

Table 2. Cost breakdown by chemical class in dollars per season per acre. Costs with different letters within a row are significantly different at .05 level.

County	Year	Cost/Acre	Pyrethroid	OP	Combination
San Joaquin	2004	N	19	119	82
		$	101.65 A	147.17 A	189.72 B
	2003	N	16	128	98
		$	69.17 A	138.16 B	183.07 C
	2002	N	19	99	82
		$	83.75 A	121.95 A	177.02 B
San Joaquin Average			84.86	135.76	183.27
Tehama	2004	N	3	23	12
		$	57.95 A	122.6 A	225.73 B
	2003	N	3	16	11
		$	115.48 A	158.95 A	221.00 A
	2002	N	6	25	10
		$	83.66 A	135.13 A	174.37 A
Tehama Average			85.70	138.89	207.03
Total Average			85.28	137.32	195.15

Note: N = sample size, $ = cost

Table 3. Mite costs in relation to chemical strategy and overall total insecticide material costs. For mite cost as average % of total, values with different letters within a row are significantly different at .05 level.

Percentages	County	Year	Pyrethroid	OP	Combination
% growers treating for mites	San Joaquin	2004	74	71	85
		2003	56	80	84
		2002	58	71	83
	Tehama	2004	67	52	83
		2003	67	81	82
		2002	67	56	90
Mite cost as % of total material cost (application costs excluded)	San Joaquin	2004	69 A	46 B	43 B
		2003	76 A	46 B	44 B
		2002	65 A	50 B	44 B
	Tehama	2004	82 A	36 B	45 B
		2003	67 A	43 A	40 A
		2002	58 A	33 B	38 B

Table 4. Percentage of growers who would find the alternative approach of equal of less expense than their current costs.

Pheromone a.i.:		5ai CM-f		10ai CM-f	
Product:		Success	+ Confirm	Success	+ Confirm
Secondary Pest Costs:		Eliminated due to narrow spectrum nature of success			
San Joaquin	2002	64	49	36	26
	2003	61	44	34	25
	2004	68	54	44	34
	Average	64	49	38	28
Tehama	2002	40	31	29	19
	2003	40	34	29	20
	2004	35	26	21	21
	Average	38	30	26	20
Product:		Malathion	+ Confirm	Malathion	+ Confirm
Secondary Pest Costs:		Halved due to low use rate of broad spectrum OP, Malathion			
San Joaquin	2002	49	36	23	17
	2003	49	33	24	15
	2004	57	43	35	26
	Average	52	37	27	19
Tehama	2002	38	29	24	12
	2003	46	31	26	17
	2004	33	23	23	19
	Average	39	28	24	16

Table 5. Sensitivity analyses: rounded averages of percentage of growers economically preferring a given alternative approach given changes in pheromone ai and secondary pest costs; averaged over 2002-2004.

% Growers preferring agroecological approach if:		Pheromone: 5 grams ai			Pheromone: 10 grams ai			Change in economic preference % due to:						
								Sensitivity to pheromone ai			Sensitivity to secondary pest cost			
								5ai vs. 10ai			5ai	10ai	5ai	10ai
Secondary pest costs are:		Eliminated	Halved	No change	Eliminated	Halved	No change	Eliminated	Halved	No change	Halved minus No change		Eliminated minus No change	
San Joaquin	Success	64	49	34	38	26	16	26	22	17	15	10	31	22
	+Confirm	49	36	22	28	17	8	21	18	14	14	10	27	21
	Average	57	42	28	33	22	12	24	20	16	14	10	29	21
	Malathion		52	36		27	17		25	19	16	10		
	+Confirm		37	24		19	8		18	16	13	11		
	Average		45	30		23	13		22	18	15	11		
Tehama	Success	38	32	24	26	20	13	12	12	11	8	7	14	13
	+Confirm	30	26	17	20	14	9	10	12	8	9	5	13	11
	Average	34	29	21	23	17	11	11	12	10	9	6	14	12
	Malathion		39	32		24	17		15	15	7	7		
	+Confirm		28	21		16	9		12	12	7	7		
	Average		34	27		20	13		14	14	7	7		

Table 6. Breakdown of percentage of growers economically preferring an agroecological strategy by chemical class. Averaged over 2002-2004.

Chemical Class:				**Pyrethroid**	**OP**	**Combination**	**Pyrethroid**	**OP**	**Combination**	**Pyrethroid**	**OP**	**Combination**
Secondary Pest Cost:				Eliminated			Halved			No Change		
San Joaquin	Average Sample Size		N	18	115	87	18	115	87	18	115	87
San Joaquin	5ai	Success	**Percentages**	23	63	77	14	45	63	9	29	47
San Joaquin	5ai	+Confirm	**Percentages**	18	45	63	11	31	48	7	17	33
San Joaquin	5ai	Malathion	**Percentages**	23	62	78	14	47	68	9	30	49
San Joaquin	5ai	+Confirm	**Percentages**	18	45	61	11	32	51	7	18	35
San Joaquin	Average		**Percentages**	21	49	64	13	34	52	8	20	36
San Joaquin	10ai	Success	**Percentages**	11	33	52	7	21	38	4	11	26
San Joaquin	10ai	+Confirm	**Percentages**	5	24	40	2	12	27	0	5	13
San Joaquin	10ai	Malathion	**Percentages**	11	32	52	7	22	39	4	12	27
San Joaquin	10ai	+Confirm	**Percentages**	5	24	40	2	14	30	0	5	15
San Joaquin	Average		**Percentages**	8	34	51	5	22	39	2	12	26
Tehama	Average Sample Size		N	4	21	11	4	21	11	4	21	11
Tehama	5ai	Success	**Percentages**	17	35	64	17	28	52	0	22	43
Tehama	5ai	+Confirm	**Percentages**	17	27	52	0	26	46	0	20	22
Tehama	5ai	Malathion	**Percentages**	17	36	64	17	35	61	0	29	55
Tehama	5ai	+Confirm	**Percentages**	17	26	52	0	26	52	0	20	37
Tehama	Average		**Percentages**	17	31	58	9	26	45	0	20	33
Tehama	10ai	Success	**Percentages**	6	24	46	0	19	37	0	19	12
Tehama	10ai	+Confirm	**Percentages**	0	19	36	0	16	21	0	10	12
Tehama	10ai	Malathion	**Percentages**	6	26	46	0	22	46	0	20	21
Tehama	10ai	+Confirm	**Percentages**	0	21	34	0	17	24	0	12	12
Tehama	Average		**Percentages**	3	23	41	0	21	40	0	18	21

N = average sample size, not percentage

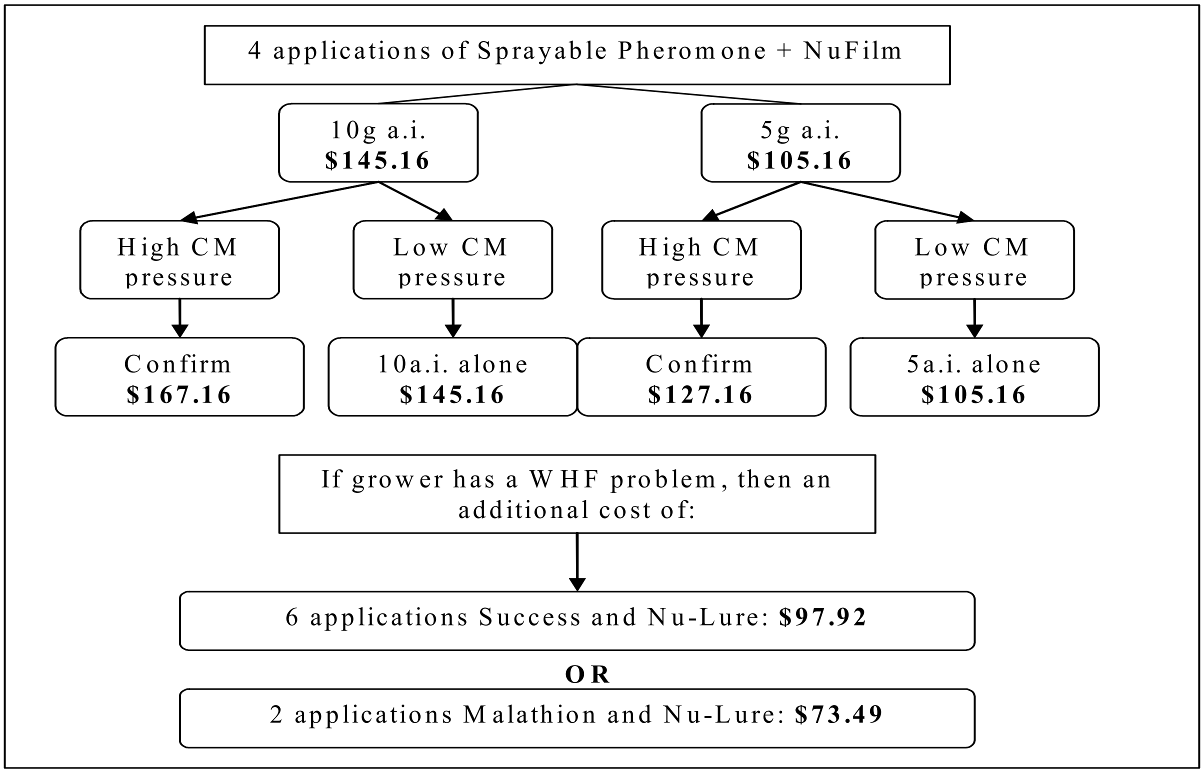

Figure 1. Costs of estimated alternative strategies: total cost per season per acre including material and application costs.

ASSESSING LONG-TERM VIABILITY OF THE WILLIAMSON ACT IN CALIFORNIA

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Abstract
The Williamson Act is the flagship conservation program protecting California's world-renowned farmland. This act, though, is an incentive-based, voluntary program that is easily compromised by the landowners' prospects of cashing in on development dollars. The differential tax assessment method for protecting land exists nationwide, but it still must compete with the vast amounts of money that developers can offer these landowners. This temptation is exacerbated by difficulties farmers on the periphery of urban areas already face. This paper outlines just how effective the act has been in protecting these lands. In particular, parcels near urban areas are tracked over time as they enter into and exit this act in the path of urban expansion. These edge areas are of particular importance since the most valuable farmland tends to be closest to urban centers, while the hinterlands tend to be less valuable grazing pasture. This paper sheds light on the continuing viability of not only the Williamson Act but all such programs since they exist nationwide. This paper offers an important understanding of the geographical applications and consequences of such policies, and how they play out on the ground. Finally, future scenarios are explored using cellular automata modeling.

Key words: farmland, conservation, rural, GIS, integrated systems

AN INTEGRATED APPROACH TO AGRICULTURE AND THE ENVIRONMENT AT THE STATE LEVEL

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Abstract

State departments of agriculture play an important role in efforts to enhance environmental protection and natural resource conservation. The California Department of Food and Agriculture, the Office of Agriculture and Environmental Stewardship, takes a multidisciplinary approach to address environmental and resource management issues facing agriculture. The mission of the office is to conserve and protect natural resources and the environment, upon which agriculture depends, through strategic alliances and partnerships. Objectives of the office are to develop and communicate department policies on environmental conservation and protection issues, and implement sound public policy in the area as related to agriculture. The office uses several implementation strategies: identify and prioritize environmental conservation and protection issues; identify the department's roles and responsibilities in addressing environmental conservation and protection issues; provide accurate and timely information to partners, stakeholders, and the general public; and provide support to the agricultural community to identify, develop, and implement actions that enhance environmental conservation and protection. This paper describes several case studies of successes and failures regarding how the office has addressed specific issues including water and air quality, biofuels, habitat and endangered species, agricultural land protection, and pest management, and makes specific recommendations for improving public policy.

Key words: agriculture, environment, stewardship, public policy, integrated systems

CAPITALIZING ON VALUE-ADDED AGRICULTURE: THE ENVIRONMENT

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Abstract

In an urbanizing state such as California, agriculture is frequently seen by urban residents as the cause of many environmental problems. In part, due to this perception, California agriculture is increasingly subject to costly regulations that threaten the economic viability of the industry. However, agriculture can and does provide many public benefits beyond food and fiber. These "value-added products" can include energy from waste, improved wildlife habitat, flood-water management, groundwater recharge, scenic open space, carbon sequestration, recreation, and others. Few markets currently exist for these environmental products, and limited public funds are available to compensate private landowners for the costs of providing them. This presentation will describe an emerging public policy paradigm in California of a *working landscapes* approach to environmental protection and enhancement. As used in this presentation, a working landscape is a place where agricultural endeavors are conducted with the objective of maintaining the viability and integrity of the landscape's commercial and environmental values. The presentation will review the California Department of Food and Agriculture's work to promote a working landscapes approach among the state's natural resource and environmental protection agencies. Recommendations to support this approach in the next farm bill will be presented.

Key words: agriculture, environment, working landscapes, stewardship, farm bill, integrated systems

AGROECOLOGY IN ACTION: HOW USEPA LINKS POLICY WITH PRACTICE BY SUPPORTING THE EXTENSION OF INTEGRATED FARMING SYSTEMS

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Abstract

Lacking a Congressional mandate to regulate agriculture's environmental impacts, the USEPA has supported local initiatives in integrated farming systems' research and extension. This support has emerged through the initiative of regional USEPA staff when they have compiled a systematic analysis of agriculture's environmental impacts. Enhancing agriculture's environmental stewardship is possible, but requires re-orienting and re-organizing agricultural science so that it facilitates grower, consultant, and commodity organization participation through agroecological partnerships. Conventional "transfer of technology" extension practice cannot create the development of integrated farming systems necessary to advance sustainability. This paper reports four years of field research, including more than 250 interviews with agricultural scientists, U.S. EPA, and other regulatory agency staff, growers, consultants, and agricultural commodity group staff in four states. It documents innovative social networking strategies these participants developed to put agroecology into action or to extend integrated farming systems perspectives, and the critical role the U.S. EPA has played in them. These initiatives have been particularly effective in California's perennial crops, especially wine grapes, almonds, and pears, where organophosphate pesticide-use reduction has reached 80%. To take full advantage of the potential of agroecological partnerships, Congress must provide U.S. EPA additional administrative and policy tools.

Key words: agroecology, environmental policy, integrated farming systems, extension practice

Introduction

The United States has never had an explicit, systematic environmental policy for agriculture, despite its serious and extensive impacts. Congress has never shown much interest in regulating the environmental consequences of agriculture, in large part because it has found the persistent cultural myths about family farmers and the national virtues they exemplify politically useful (Browne et al., 1992). USEPA faces particular challenges in regulating agriculture because the farming practices shaping the quantity, media, and impacts of pollution are distinct by crop, region, and specific ecological context, frustrating consistent enforcement. The kind of agriculture (annual crops, perennial crops, animal husbandry) determines the kinds of pollution (nutrients, soil erosion, agrochemicals) most likely to leak out of the farming system into the broader landscape. Local soil, moisture, and geological conditions have a tremendous effect on the severity and scope of pollution, and operation-specific management practices can result in highly variable environmental impacts, even within the same kind of cropping or animal production system.

Regional offices of the USEPA in the West have supported local initiatives in integrated farming systems' research and extension. This support has emerged through the initiative of regional USEPA staff when they have compiled a systematic analysis of agriculture's environmental impacts. Enhancing agriculture's environmental stewardship is possible, but requires collaborative multi-stakeholder participation in agroecological partnerships. Conventional "transfer of technology" extension practice cannot create the development of integrated farming systems necessary to advance sustainability. This paper reports on USEPA participation in innovative social networking strategies developed to extend integrated farming systems strategies, or to put agroecology into action. It argues that to address agriculture's environmental impacts in a coherent way, the U.S. Congress must pass enabling legislation that will allow USEPA to play a stronger role in ecosystem management (Warner, 2006b).

Methods

This paper reports qualitative research into the social relations between USEPA agency staff and social networks of growers, consultants, scientists, and growers' organizations pursuing pollution prevention goals in the Western U.S. Using in-depth interviews among growers, scientists, regulators, and agency staff, it highlights creative efforts by agency staff to address agricultural pollution despite absence of a legislative mandate to regulate agriculture. Three years of field interviews in California provided data sources for this research. Primary sources of information are semi-structured interviews with 32 partnership leaders. This is supplemented by: personal interviews with 97 other participating growers, managers, scientists, and grower organization staff; 13 focus groups with 84 participating growers, extension agents, scientists, and grower organization staff; and participant observation at 34 partnership-related meetings. Data from this field work was analyzed and reported in a dissertation (Warner, 2004), and supplemented with 18 interviews with partnership participants in three other states.

The problem of agro-environmental regulation

Congress has never given the USEPA a clear mandate to address agricultural pollution, even as deleterious effects on water quality have become incontrovertible (U.S. Geological Survey, 1999). Laws regulating pesticides and non-point source water pollution have been the two key anchors for creative efforts on the part of entrepreneurial USEPA staff who have worked to meet pollution prevention goals. The USEPA was created with a whole cluster of environmental laws, but two of them stand out for the purposes of regulating agricultural pollution (Andrews, 1999). Congress passed the Federal Environmental Pesticides Control Act in 1972, which transferred responsibility for pesticide registration and regulation to the USEPA, in large part to address charges that the U.S. Department of Agriculture suffered from a pro-pesticide bias (Bosso, 1987). Congress assigned the USEPA responsibility for pesticide evaluation and registration, but regulatory enforcement of pesticide use was still in the hands of the states, with the USEPA supervising. In the same year, Congress passed the Federal Water Pollution Control Act Amendments, better known as the Clean Water Act. American cities and industry have made impressive progress in controlling point-source or end-of-pipe water pollution, and agricultural nutrients are now the greatest source of non-point-source water pollution (U.S. Geological Survey, 1999).

Agriculture can pollute several environmental media: air, surface water, and groundwater quality, often simultaneously, and sometimes from different activities. Environmental impacts may be temporally or spatially distinct from the activities that cause them, as is the case with surface and groundwater pollution. Decisions about agricultural practices in the United States are made by 2 million farm operators. Each of these factors presents a significant obstacle for typical environmental regulatory strategies, confounding the regulatory uniformity required of an equitable process (Rosenbaum, 1994).

Even as *Silent Spring* (Carson, 1962) stimulated new environmental policies, U.S. agricultural pesticide use grew dramatically, reaching a billion pounds per year in 1976 and fluctuating around that level ever since (Aspelin, 2000). California's specialty-crop agriculture has used a disproportionate amount of the nation's total pesticides, roughly 20–25 percent (Aspelin and Grube, 1999). After DDT was banned, many growers compensated by switching to organophosphate pesticides. These insecticides do not bioaccumulate and threaten top predators as did DDT, but they are acutely toxic, and increasing reliance on organophosphates meant greater acute health risks to growers and farm workers (Wright, 1990). California's San Joaquin Valley has the maximum concentration of many pesticides among all of the U.S. watersheds studied by the U.S. Geological Survey: pesticides were detected in 69 percent of the groundwater samples collected from the eastern San Joaquin Valley (U.S. Geological Survey, 1998a). A companion report on the Sacramento River found that watershed to generally be in better shape, although it did find that agricultural streams here have some of the nation's highest concentrations of the insecticide diazanon (U.S. Geological Survey, 2000).

Twenty years after the USEPA's creation, attention within the agency began to focus on agriculture's environmental problems. The USEPA was initially created with a legislated shotgun marriage of existing media (air, water) and category (pesticides, solid waste) programs. William Reilly, USEPA Administrator under President George H. W. Bush, directed his staff to undertake regional analyses of environmental problems to determine gaps they needed to address. The agency increasingly framed these as pollution prevention initiatives, and this shifted attention from end-of-the-pipe pollution management to the reduction or elimination of potential pollutants, especially hazardous or toxic materials (Gottlieb, 2001). It also launched initiatives to work with other federal agencies with existing authority to manage resources. Under Reilly's tenure, the USEPA also emphasized public sector/industry partnerships to promote voluntary pollution prevention (Andrews, 1999).

Concurrently, the National Research Council (1993) issued a report titled *Soil and Water Quality: An Agenda for Agriculture*, which called for a systems approach to prevent pollution while protecting farming productivity. It argued that integrated farming system plans should become the basis of federal, state, and local soil and water quality programs. The report observed that-

> Inherent links exist among soil quality conservation, improvements in input use efficiency, increases in resistance to erosion and runoff, and the wider use of buffer zones. These links become apparent only if investigators take a systems-level approach to analyzing agricultural production systems. The focus of such an analysis is the farming system, which comprises the pattern and sequence of crops in space

> and time, management decisions regarding the inputs and production practices uses, management skills, education and objectives of the producer, quality of the soil and water, and nature of the landscape and ecosystem with which agricultural production occurs (p 107-8).

This report became the most influential agricultural environmental resource protection agenda during the 1990s. It did not explicitly define "integrated farming system," admitting that variability in cropping systems, ecosystems, and regional contexts made a singular definition impossible, but it did hold point a general direction for agricultural resource protection, one with remarkable parallels to the USEPA's pollution prevention approach.

During the 1990s, stimulated by these new conceptual approaches, in at least USEPA Regions IX and X (the Pacific Southwest and Northwest), staff conducted systematic analyses and determined that agriculture was the greatest unregulated source of pollution (Warner, 2006b). Lacking statutory authority to regulate agricultural pollution but aware of the potential of community-based environmental protection approaches (USEPA, 1997), staff in these regions looked for local initiatives that might provide new opportunities for pollution prevention in California and Washington State. During the Clinton administration, the U.S. Department of Agriculture set new goals for implementation of IPM, but passage of the Food Quality Protection Act (FQPA) in 1996 was the most important agricultural regulatory initiative of that decade (Warner, 2006b). When USEPA staff encountered networks of growers seeking to make voluntary progress in this area, they discovered that by investing in them, they could achieve agency goals with carrots, not merely sticks.

Essentially all industrial farming operations pollute, and comprehensive enforcement is impossible. Laws such as the Clean Water Act and the FQPA provide a framework for environmental regulatory agencies at federal and state levels, but their limited resources leave all but the most egregious environmental offenses unaddressed. Agriculture's widely distributed and independent decision makers, managing varied farming systems in highly variable ecological contexts, frustrate regulatory enforcement models. For these reasons, developing incentive systems of collaborative voluntary efforts to develop integrated farming systems hold more promise for resource protection.

California: partnering with ecologically informed agricultural initiatives

During the early 1990s, several informal groups of growers and crop-specific semi-public commodity organizations, recognizing that agriculture was under considerable if diffuse public pressure to improve its environmental performance, began initiatives to reduce pollution. In California, the most successful and enduring of these initiatives took place among almond, pear, and winegrape growers. These primarily addressed insecticides. In Washington State, some annual growers recognized the problems with farming practices that left the soil vulnerable to wind and water erosion. Other initiatives began in dairy and corn/soy systems in the upper Midwest. These partnerships – their origins, practices, extension strategies, and impacts- are analyzed in detail elsewhere (Warner, 2006a; Warner, 2006b), but several of their key traits are summarized here.

An agroecological partnership is defined to be "an intentional, multi-year relationship between at least growers, a grower's organization, and one or more scientists to extend agroecological knowledge and protect natural resources through field-scale demonstration." These initiatives have gone beyond integrated pest management, to take an integrated farming system approach to pollution prevention, as recommended by the National Resource Council. Because of their system approach, integrated farming systems merit the term agroecology (Altieri, 2002; Warner, 2006b). This model contains traditional elements of extension, but deliberately configures them to more effectively promote agroecological knowledge. The scale of grower, scientist, and organizational participation in agroecological partnerships, plus the degree of entrepreneurial leadership they have invested in them, are without parallel in California over the past two decades. A total of 32 partnerships in 16 commodities were launched in California between 1991 and 2003. The agroecological partnership model became the chief strategy for extending alternative agricultural knowledge in California during the decade following 1993.

The Biologically Integrated Farming System (BIOS) partnership among almond growers was the first high-profile, successful agricultural partnership in California (Dlott et al., 1996). BIOS facilitated social or group learning about the interactions between components of their farming system (Pence and Grieshop, 2001). The initial partnership consisted of the non-governmental organization Community Alliance with Family Farmers

(CAFF), staff from the University of California Sustainable Agriculture Research and Education Program (SAREP), and a University of California farm advisor. They set out to improve upon conventional extension practice by re-imagining how traditional participants related to each other in the generation of agricultural knowledge. To fund almond BIOS, CAFF contacted Augie Feder, a new USEPA staff member in the Region IX office, which had hired Feder because its analysis had identified agriculture as the top source of California's unmitigated pollution. Regional USEPA leadership recognized that their traditional existing media (air, water) and category (pesticides, solid waste) programs were not sufficient, so they wanted to try a new approach. Feder had heard of an initial study demonstrating the viability of reduced pesticide strategies and recognized it represented the kind of systems-based, pollution-prevention approach the USEPA needed to support.

Feder brought to bear knowledge of the latest science policy for addressing agricultural pollution, but also documentation of the problem of the organophosphate diazinon. It was and is a priority pollutant in the western United States. Almond growers were the top users nationwide of diazinon, followed by prunes, even though only a fraction of growers apply it annually. The environmental problem of diazinon focused regulatory agency interest in alternatives. Feder secured some initial funds for almond BIOS, and then when the first year's results indicated dramatic reductions in agrochemical use, he argued successfully that support for this kind of community-based, grassroots project achieved the agency's pollution-prevention goals far more efficiently than regulatory actions. His supervisors encouraged him to partner with BIOS and other voluntary initiatives to prevent pollution and achieve agency goals.

BIOS brought wide attention to the possibility of alternatives, both within the agricultural and regulatory communities. BIOS demonstrated that alternative extension practices could facilitate alternative agriculture. Other partnerships in winegrapes, pears, and stonefruit had been initiated earlier, and partnerships in prunes and in cotton started while BIOS was still in its infancy. The quick and evident success of BIOS caught the attention of the regulatory community. CAFF insisted that what they had demonstrated to be successful in almonds could be reproduced in other commodities. The example of BIOS and the advocacy of CAFF stimulated legislators, public agency officials, and philanthropic foundations to fund and create funding programs for more partnerships. The two primary funding programs have been SAREP's Biologically Integrated Farming Systems and the Department of Pesticide Regulation's Pest Management Alliance (PMA) program, but other funders emerged as well (Warner, 2006b).

USEPA has been a generous funder of SAREP's Biologically Integrated Farming Systems program. USEPA staff recognized that it could achieve through voluntary partnership initiatives what was not possible through regulatory initiatives. In 1996, Congress passed the FQPA. It established a thorough review of pesticides and threatened to ban organophosphates, causing considerable anxiety among growers and agricultural organizations. The FQPA also provided funding for alternative pest-management approaches through the USEPA and the USDA, which have funded various partnership activities across the country seeking alternatives to hazardous pesticides. Ten of the 32 California partnerships were launched within two years of the FQPA's passage.

The California Department of Pesticide Regulation, located in the state's Environmental Protection Agency, initiated its own program, the Pest Management Alliance (PMA). It is the first and only state pesticide agency-initiated pest-management extension effort in the United States. Between 1998 and 2002, the DPR sponsored eight PMA grants that qualify as multi-year partnerships. The PMA partnerships are based on the public/private industry partnerships developed between the USEPA and manufacturers using USEPA's language of risk assessment and reduction.

These partnerships have had notable successes in some commodities and much less in others. Generally, perennial crop growers have taken advantage of partnership activities, more so than other growers (Warner, 2006a). Winegrape growers have organized six partnerships, the most of any commodity (Warner, in press). Significant reductions in FQPA-targeted pesticide use has occurred in every winegrape region where partnership activities have taken place. The almond industry has documented the greatest voluntary volume reduction of organophosphate use in California history. Pear growers reduced organophosphate use faster than any other commodity in the history of California agriculture (for an analysis of pesticide use reductions, see Warner, 2006b).

Washington State: listening and partnering

USEPA staff in the Seattle regional office identified the Columbia Plateau's agro-environmental problems during the mid 1990s. When they analyzed Washington State air, water, and land pollution—plus habitat loss—they discovered that agriculture was the least regulated source. During the Clinton Administration, the Seattle office of the USEPA secured funding for several community-based environmental protection initiatives, efforts to work cooperatively with local agencies and citizen groups to address environmental problems that are beyond the scope of typical regulatory devices (U.S. Environmental Protection Agency, 1997). This approach identifies geographic regions with environmental problems unaddressed by existing programs, and provides institutional support, coordination, and some funding, for local efforts.

Persuaded by data, the Seattle USEPA office created the Columbia Plateau Agricultural Initiative (CPAI) in 1997, drawing from existing agency staff. Chris Feise, then an extension specialist from the Pacific Northwest land-grant universities serving as a liaison to the agency, insisted that CPAI staff first conduct a listening tour of the farmers and agricultural institutions in the region. He had extensive experience with sustainable farming systems, but realized how much USEPA staff had to learn about agriculture if this initiative had any chance to bear fruit. Plans for the one-week tour included 30 meetings in five counties with more than 90 people. For several staff members, this was the first time ever seeing the Columbia Plateau or visiting a farming operation. They learned the importance of understanding the social institutions in agriculture. The listening tour heard an earful about the credibility problems of regulatory agencies. Farmers explained some of their fears: that the agency rendered decisions affecting the agricultural community without their input; that these regulations will drive them out of business and a way of life; and that costly efforts to improve their environmental practices will only be rewarded with more regulations. The growers convinced USEPA staff that the lack of communication between farmers and agency staff would jeopardize their credibility, as well as stable food production in the region.

The listening tour discovered that tremendous changes were taking place in Washington State agriculture, led by bright, educated, knowledgeable, and innovative people. The staff on tour were challenged by a group of local farmers to back up their stated goals by funding progressive agricultural initiatives. A local network of farmers had developed a research plan for a demonstration project that was the most holistic approach to agro-environmental problems the staffers had seen. The CPAI team had known they were going to have to create new approaches to working with the rural communities, but it was surprised to discover how difficult it was to persuade its own USEPA colleagues of the merit of a constructive engagement with agriculture. They discovered how deeply entrenched a law enforcement approach was in the culture of their own agency. To succeed, the USEPA was going to have to understand much more about the structure, logic, and economics of agriculture—indeed the culture of agriculture.

Over the next several years, the Seattle office contributed more than $600,000 to agroecologically informed research and extension, including pest management strategies, crop rotations, and water management. CPAI helped the USEPA learn that progress toward pollution-prevention goals in agriculture was possible. Despite feelings of ambivalence held by partnership participants, a recent analysis of the CPAI initiative determined that growers, the USEPA, and other public sector participants believe it was successful, and an important first step into a new way of thinking and engaging in community-based pollution-prevention initiatives (Feise and Lovrich, 2003). Both regulators and growers observed that the "listening tour" may have been the most significant component of their partnership because it laid the foundation for collaboration.

Conclusion: agency initiative in the absence of coherent policy

Several entrepreneurial approaches on the part of environmental agencies emerged in the 1990s as they began recognizing that traditional regulatory efforts did not adequately address agricultural pollution issues, especially non-point-source water pollution. Regional offices of the USEPA, plus the California EPA, provided funding, leadership, and technical assistance to agroecological partnership activities. These emerged as agency personnel sought more community-based, multi-disciplinary, and integrated approaches. Staff also recognized in a new way the importance of understanding the participatory social processes necessary to support voluntary environmental initiatives (Feise and Lovrich, 2003).

Agency personnel welcome the opportunity to be seen as playing a constructive role in the agricultural community, and agricultural organizations seize opportunities to represent themselves to regulatory agencies as being environmentally responsible. Yet, the entry of regulatory agencies into extension activities provokes ambivalent feelings among both parties. Agency personnel have asserted the primary function of their agency is to enforce environmental laws, even as they provide to some organizations of growers who are essentially in violation of the Clean Water Act. Agricultural organizations welcome the funding regulatory agencies' dollars, but have had to reassure growers that they are not "negotiating with the enemy." USEPA staff generally perceive the partnership approach to have many limitations, but all the other tools presently in their regulatory toolbox have proven to be even less effective.

Recently the agency has concentrated its resources to support the development of economic incentives to reward growers through the marketplace for adopting suites of practices that partnerships have developed. Protected Harvest is a non-governmental organization that certifies local groups of growers who have developed standards for reducing pesticide impacts and making progress toward environmental goals. Their label accords legitimacy to some of the growers' groups who have sponsored partnerships and allows them to charge a premium price. This means that groups of participating growers are able to capture further benefits from their investment in learning about practices developed by agroecological partnerships. USEPA Region IX awarded Protected Harvest a $425,000 grant in 2005 to develop standards for dairy, almonds, tomatoes, and stone fruit in California.

Protected Harvest provides a critical link between agroecological initiatives and the public, and it provides a service to society by allowing consumers to vote with their dollars. Some of the consuming public has lost trust in the American industrial food system, because the agricultural industry and policy makers have for too long failed to address its negative environmental and health impacts. Protected Harvest provides economic rewards for groups of entrepreneurial growers, and that is good. It helps environmentally conscious consumers to have confidence in the health and stewardship of some food products, which is also good. These achieve general agency goals for pollution prevention.

But from a policy analysis perspective, public agency support of Protected Harvest should be seen as insufficient to address the absence of coherent U.S. agro-environmental policy. USEPA actively supports groups of growers who want to undertake voluntary change, but this does not address the environmental consequences of irresponsible growers, those uninterested in practicing stewardship. Anecdotal evidence suggests that a very small number of growers may be responsible for California agriculture's most serious pesticide problems, and market incentives for improved stewardship are unlikely to interest these growers. In California, regional water control boards are increasingly scrutinizing agricultural runoff, but it remains to be seen whether any actual enforcement action take place.

Congress has never provided proper direction or authorization for the USEPA to help agriculture achieve national water and air pollution prevention goals. This is a major impediment for the agency, resulting in one of the most glaring gaps in U.S. environmental protection policy. Agriculture does pose special problems for environmental regulation, but its environmental problems are serious and still not adequately addressed. Does the American public really wish to not regulate agro-environmental problems?

The regional agency initiatives described in this paper are remarkable for their creativity in the absence of legislative mandate. For a genuinely healthier relationship between food, farming, and society in the United States, we need a broad, vigorous debate about how policies can foster the kind of agriculture we want and the coherent environmental policy needed to support that. The USEPA should be given regulatory authority to foster healthy, resilient ecosystems, through its own initiatives and in partnering with the Department of Agriculture and other agencies.

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TRACK 2
CLEANUP AND TECHNOLOGY TRANSFER

MONITORING OF REACTIVE ORGANIC GAS EMISSIONS FROM VARIOUS MANURE-HANDLING METHODS AT CALIFORNIA DAIRIES

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Abstract
A preliminary study of ROG emissions related to dairy operations was conducted at two central California locations in 2003-04. The monitoring and modeling methods developed for that project will be applied to a more comprehensive study that began fall 2005 and will continue through 2008. Primary funding for the project is from the California Air Resources Board with matching funding from the CSU Agricultural Research Initiative. New sampling and analytical methods are to be added to the procedures used in the preliminary study. The first sampling periods are to be used to test and validate those new methods. The sampling and analytical methodologies have been tested at six dairies in sampling done in winter, 2006 and again in spring-summer, 2006. Field sampling procedures and some preliminary data will be presented here. Six dairies with different manure-handling systems have been selected for the three-year monitoring program. Four of the dairies use flush lanes and a large volume of water to collect the manure and treat it in lagoons prior to applying it to cropland. The lagoon systems range from a single large unit to a sequence of four ponds with mechanical circulation systems. The other two dairies do not use water to collect and treat manure. One has a vacuum truck that delivers it to a digester. The other scrapes the lanes into a pit where it is pumped into a large trailer and taken to a field where the slurry is injected below the soil surface of fallow cropland. The sites will be sampled three times, winter, early summer and early fall, each year to determine emission differences due to seasonal variation. The monitoring program will include day and night or continuous sampling to determine diurnal emission differences. Emissions will be estimated using both ambient canister sampling (upwind and downwind) as well as flux chambers at appropriate locations. The components of the dairies to be monitored include the animal housing, manure collection system, manure separation, treatment and storage systems, feeding and feed storage, and land application of effluent and manure. Analysis of the gas samples will be done at UC Irvine by Dr. Blake as well as at CSU Fresno in the CWI lab. Emissions will be modeled using the Gaussian plume dispersion model, ISC-ST v.3. A companion study with cooperators from the University of New Hampshire will collect data related to N and C in the manure at the six dairies to be used in the development of a process-based model called DN-DC to predict the effect of management on the N in the system.

Key words: dairy emissions, ROG emissions, agricultural air quality

VOLATILE ORGANIC COMPOUND EMISSIONS FROM DAIRY OPERATIONS

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Abstract
Air quality in the San Joaquin Valley ranks as the worst in the country, and dairies are listed as the greatest source of volatile organic compounds (VOCs), followed by exhaust emissions from trucks and cars. Official emission estimates of dairy VOCs are highly uncertain. Several studies were funded by air regulatory agencies to study dairy VOC emissions. Two of these studies were conducted at UC Davis to study emissions from dairy cows, waste, and feed in sealed environmental chambers and large dirt-floored bio-bubbles. While our studies and additional studies conducted by other investigators have just recently been finalized, preliminary results suggest fermented cattle feed appears to be the largest source of dairy-related VOC emissions; manure in drylot corrals and enteric fermentation by the cows appear to be additional important sources of VOC emissions; VOC emissions from manure storage ponds (studied by a non-UC consultant) appear to be far less significant than previously thought. Those unexpected results may affect thinking and practices of California regulators and dairy operators trying to reduce air pollution. This information is urgently needed by the $4.6 billion, 1.7 million-cow California dairy industry - the largest in the world - as dairy producers try to comply with strict new pollution rules.

Key words: dairy, VOC, emissions, animal production - air quality

REACTIVE ORGANIC GASES AND AMINE EMISSION ESTIMATES FOR NORTHERN CALIFORNIA DAIRIES: DIRECT MEASUREMENT USING THE USEPA SURFACE EMISSIONS ISOLATION FLUX CHAMBER

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Abstract

The Central California Ozone Study (CCOS) group has sponsored a multi-phased field study managed by the California Air Resources Board (CARB) to evaluate air emissions of reactive organic gases (ROGs) and ammonia/amine compounds from flushed-lane dairies in northern California. The goal of the research was to provide process-specific dairy emissions data and "per cow" emission factors for use in improving emission estimates required for State Implementation Plans (SIPs) and Senate Bill 700 (Florez). Air emission measurements were performed using the USEPA surface emissions isolation flux chamber (flux chamber), and gas samples were collected from the flux chamber for quantitative analysis of ROG/amine compounds at 10 common "unit processes" found at two, flushed-lane dairies with a focus on feed bunkers, turnouts, and lagoons. Flux data were collected with the intent of averaging data-per-unit processes and generating average or representative ROG/compound emissions per process. A simple average of process data was appropriate based on the sample collection design. Flux data are reported as unit emission factors (ROG and species) for each unit process or unique area source, as well as area emission estimates per process, which were summed per test area to generate site dairy emissions per process. All process emissions data were then summed for total dairy emissions, and from this total, per-cow emission rate data were obtained by dividing dairy emission by the number of cows in the dairy. Diurnal variability was also studied and used to generate representative annual emission estimates. The flux data and per-cow emission factor data were compared to earlier studies conducted by EPA Region 9 in northern California and the South Coast Air Quality Management District in southern California.

Key words: dairy cow emissions, species emissions, USEPA flux chamber, ROG dairy emissions, amine dairy emissions, animal production - air quality

GASEOUS EMISSIONS FROM CALIFORNIA BROILER PRODUCTION HOUSES

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Abstract
Methodology is developed to analyze emissions from poultry production facilities utilizing standard source test methods. A stack was designed and fabricated to meet engineering testing criteria and was utilized to quantify emissions from exhaust air from a typical California broiler house. Emissions of ammonia and organic gasses were measured periodically during the 55-day broiler production cycle, including 45 days of production and 10 days between broods. Several methods were used for analysis of organic gasses and it was found that a gas chromatography/mass spectrometry analysis from samples collected in evacuated summa canisters was more useful than hydrocarbon methods for the low concentrations and complex gas mixtures encountered. An emissions factor of 6.5 g bird^{-1} raised (0.0143 lb bird^{-1}) for ammonia and 2.8 g bird^{-1} raised (0.0061 lb bird^{-1}) for total organic gas is estimated. Several compounds (including acetone, dimethyl disulfide, ethanol, methanol, propane, and vinyl acetate) dominate the mass of organic gasses emitted from the house, according to mass spectrometer analysis. These may be from distinct sources within the house. Estimated emissions factor for reactive organic gas (volatile organic compounds with ozone-forming reactivity) is 1.7 g bird^{-1} raised (0.0037 lb bird^{-1}). Implications of this new information relative to regional ozone and particulate matter problems in California are discussed.

Key words: poultry production emissions, ammonia, organic gasses, ozone, animal production - air quality

ANIMAL FEEDING OPERATIONS AND WATER QUALITY – RESOURCES AND LIVESTOCK IN BALANCE

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Abstract

The Concentrated Animal Feeding Operation Rule in the Clean Water Act regulates discharge from livestock confinement areas. Water quality is a public issue involving many governmental entities, each with a different role, but none of whom are explicitly tasked with educating the regulated community. The Livestock Water Quality Education Program is a partnership among regulatory and technical assistance providers to provide an accurate source of risk-assessment information to livestock producers. WSU Extension coordinated a planning process including NRCS, EPA, Washington conservation districts, WSU, Washington Department of Ecology, and the Washington State Department of Agriculture to identify producer information needs and develop a training session for natural resource professionals on use of a water quality assessment tool, the keystone product of the partnership. The assessment tool allows a landowner to examine facility risk factors and potential mitigating practices. The planning process and training program provided a common understanding of applicable regulations and water quality principles, as well as an opportunity to discuss the variety of perspectives toward water quality regulation. Direct outreach to producers through mailings, local workshops, two Web sites with reference materials, and seminars at agricultural events has helped more than 1000 livestock producers address water quality issues on their operations.

Key words: water quality, assessment, tool, outreach, education

Introduction

The U.S. Environmental Protection Agency (EPA) released new guidelines for concentrated animal feeding operations and animal feeding operations (CAFO/AFO) in 2003. Under the new guidelines, affected CAFOs will be required to develop a nutrient management plan, implement practices to manage manure in an environmentally safe manner, conduct soil and manure testing, and keep a variety of records. The changes in the federal rule resulted in a need in Washington to provide livestock producers with a common message about state and federal water quality rules.

This paper describes an education program developed as a partnership including the Washington State Department of Agriculture, Washington State Department of Ecology, U.S. Environmental Protection Agency, Washington State conservation districts, Washington

State Natural Resources Conservation Service (NRCS), Washington State University (WSU) Extension, Washington Cattlemen's Association, and Washington State Dairy Federation. A primary goal of the education program was to provide conservation district staff with an understanding of state and federal water quality rules and guidance toward recommending specific best management practices to livestock producers to protect water quality based on identified risk factors.

Educational Methods

The education partners were convened by WSU in the fall of 2004 to begin the design of the Livestock Nutrient Management Education Program. Over the course of two days, a structure evolved that included four working subcommittees to develop a three-day water quality conference for conservation district regulatory agency staff and was entitled "Animal **Feeding Operations and Water Quality – Resources and Livestock in Balance."**

Workshop Design

It was decided that the water quality training conference for conservation and regulatory agency staff should include multiple types of education materials and be conducted in a three-day format. Use of real-farm case studies served as the core for describing conditions under which management of livestock might result in a risk of negatively impacting the quality of surface or ground water. These case studies also functioned to discuss the types of best management practices (BMPs) that would be most effective in protecting water quality. In addition to the case studies, presentations were made on topics of 1) Changing People's Behavior: It's Not All About Education by William Hallman of Rutgers University (www.foodpolicyinstitute.org) – keynote presentation intended to persuade attendees to actively engage with agricultural producers rather than serve as information brokers; 2) holistic farm management –considering nutrient management from a whole-farm perspective; 3) grazing management – management of grazing activity influences water quality criteria such as sediment, bacteria, and temperature; 4) winter management and animal health – animal health during a critical life stage is highly affected by winter manure management; 5) phosphorus index – new research indicates phosphorus may not always remained adsorbed to soil particles; 6) Washington NRCS Technical Note No. 1 – Water Quality Indicator Tools – a technical approach to calculating manure loading for larger confinement operations; and 7) livestock-influenced water quality risk assessment tool – a tool to assist livestock producers in evaluating their own risk of pollution and consider practical, targeted management solutions. An evening session was devoted to a panel of presenters on the topic of livestock access to riparian water and the implications of two Washington State rules: one guaranteeing minimum sufficient flows to ensure livestock access to surface water and the other strictly prohibiting the willful or negligent pollution of surface and ground water, no matter how insignificant. This law is easily construed to prohibit direct access of livestock and the potential "discharge" associated therewith. The panel also discussed the contentious legal issue of diverting surface water to a stock tank without a *diversionary* water right.

The Livestock Influenced Water Quality Risk Assessment Tool was developed by the EC subcommittee and was designed to be utilized by livestock producers as a self-assessment or used in cooperation with conservation district staff to make a more technical site-specific assessment of a livestock operation. This tool is explained in greater detail in a companion paper (Livestock Influenced Water Quality Risk Assessment Tool). The tool provides a series of questions related to facility condition risk factors, current management strategies to reduce waste movement, and general management factors. Answers to each question mark that factor as high- or low-risk relative to negative effects on water quality and lead the user to possible solutions if high-risk. Example: "Are there established pathways for surface water runoff from the confinement area?" A "yes" answer marks this as a high-risk factor to be considered further and recommends the user to "consider installing a berm, filter strip, or grassed waterway" and is accompanied by NRCS practice codes for additional specifications or assistance.

Real-Farm Case Studies

Eleven case studies were selected for the conference and encompassed livestock management styles and size from small/recreational farms to commercial livestock operations. Species included llama, horse, beef, sheep, and dairy. The case studies were presented in the following manner: 1) 15 minutes for the case study leader to generally define the operation with photos and or video and allude to water quality issues; 2) 25 minutes for breakout groups (10 individuals per group) to discuss a list of resource concerns and a list of solutions; 3) 10-minute period for breakout groups to report back to the whole group the issues and solutions they identified; and 4) 10 minutes for the case study leader to report actual implementation of BMPs implemented to prevent a negative impact of livestock on water quality. While in the breakout groups, a facilitator, recorder, and reporter were selected from within the group. The case studies were presented throughout the conference in a progressing degree of complexity and relative potential risk of negatively impacting water quality. Of the 11 case studies, three were presented before any risk assessment tools were presented, three utilized the Livestock Influenced Water Quality Risk Assessment Tool as part of their discussion, and four utilized the Washington NRCS Technical Note No. 1 – Water Quality Indicator Tools as part of their discussion.

Web Site

Materials from the water quality conference were made available in printed and CD format. In addition, some materials are also available at the following Web sites: http://animalag.wsu.edu and http://www.puyallup.wsu.edu/dairy/joeharrison/. A copy of the presentations and workshop materials can be obtained by contacting Joe Harrison (jhharrison@wsu.edu) or Tip Hudson (hudsont@wsu.edu).

Summary

This education project increased conservation district staff understanding of state and federal water quality rules and an awareness of when to recommend best management practices to livestock producers to protect water quality. Real-farm case studies were an effective tool to provide training on methodically assessing the potential of livestock confinement facilities to negatively impact water quality and determining appropriate, cost-effective BMPs to protect water quality.

Acknowledgements

This risk assessment information was adapted from information developed by the Animal Feeding Operation curriculum subcommittee of the Livestock Nutrient Management Program in Washington State. Committee members include Joe Harrison and Tip Hudson of Washington State University Extension; Kirk Robinson and Ginny Prest of Washington State Department of Agriculture; Chad Atkins and Lauren Stalmaster of Washington State Department of Ecology; Bobbi Lindemulder, Chuck Timblin, Jim White, Mark Crowley, Lyle Stoltman, Duane Bartels, Erin Ewald, and Bob Anderson, Conservation District staff; and Marty Chaney of the USDA Natural Resource Conservation Service.

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SAN JOAQUIN VALLEY DAIRY MANURE COLLABORATIVE: ALIGNING AGRICULTURE, ENERGY, AND ENVIRONMENTAL POLICIES AND TECHNOLOGIES TO FULLY UTILIZE MANURE AS A RESOURCE

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Abstract

California is the nation's leading dairy state, and dairy products are California's most valuable agricultural product. Over the last 30 years, the number of milk cows has risen and the number of dairies has dropped, resulting in a dramatically increased concentration of animals and manure, especially in the San Joaquin Valley, an area already facing serious challenges to air and water quality. Dairy manure contains nutrients, salts, bacteria, and organic matter that can create environmental problems when they enter surface and ground water. Cows, feed, and decomposing manure also emit air pollutants, including volatile organic compounds (precursors to formation of fine-particulate pollution and ozone), ammonia (precursor to formation of fine particulates), methane (global warming gas), and odors. The Dairy Manure Collaborative, initiated in fall 2003, seeks to comprehensively address dairy manure issues in the San Joaquin Valley. The approach is voluntary and non-regulatory and has support from a broad range of stakeholders. The collaborative seeks to fully utilize manure for fertilizer, compost and soil amendments, bedding, and as a renewable energy source. More efficient and comprehensive treatment of dairy manure will improve soil, air, and water quality; provide a source of renewable energy; and reduce regulatory pressures on dairies.

Key words: dairy, manure, energy, California, animal production policy

DAIRY PARKS - MITIGATING DAIRY RELEASES TO WATER AND EMISSIONS TO AIR WHILE PRODUCING FOOD, RENEWABLE ENERGY, AND OTHER REVENUE STREAMS

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Abstract

Peer-reviewed data and other independent assessments, including the SJV Dairy Manure Collaborative, substantiate that Bion's microaerobic biological animal waste management technology comprehensively mitigates polluting releases to water and air. Bion's process also qualifies for USDA EQIP funding. Bion's implementation plan includes retrofitting existing large dairies, as well as building integrated dairy parks, which would include renewable-energy methane from animal waste coarse solids and ethanol solubles; and ethanol from corn with wet distillers grains fed to cows whose milk goes to either fluid milk or an on-site cheese plant where whey and water are reprocessed to make additional ethanol. Waste solids are processed in stages to yield high-value, single-cell protein and organic, non-leachable fertilizers. The effluent discharge stream could then be treated to qualify for animal drinking water or groundwater recharge. Additional revenue may come from emission-reduction credits, greenhouse gas, and nutrient credits. Standards-based environmental permitting will enable these dairies to secure environmental insurance, which will facilitate financing as will favorable economics from additional herd-stocking densities. This environmental technology will enable large-scale integrated facilities to be developed based upon economics rather than where the current race to the environmental bottom is taking place.

Key words: CAFO, manure waste management, microaerobic, dairy park, animal production policy

PRODUCER PERSPECTIVES ON ENVIRONMENTAL REGULATION

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Abstract

Agricultural producers hold well-defined personal perspectives on the efficacy and fairness of environmental regulations. A producer's standpoint has a profound influence on how an individual producer or a group of producers will respond to regulations, and will greatly influence how efficient and effective a regulatory program will be. We draw on our experience in the industry, both as a producer and as an employee of the dairy industry, to categorize suggested personal profiles of producers and how each category might respond to regulatory demands. We focus on the dairy industry and define five groupings by titling them as innovative, acquiescent, reluctant, unaware, and rebellious. Salient characteristics of each group are proposed and the unique motivation of each is explored. We discuss what we have learned about what producers want from a regulatory program. We suggest how regulatory implementation may be more effective by giving greater consideration to producer perspectives. Consideration of producer needs as well as regulatory needs at the outset of program development is important for success. In conclusion, we define the term "environmental maturity," and provide recommendations as to how a regulatory agency can effectively address the challenges associated with responding to the regulated community's perspectives.

Key words: agriculture, dairy, perspectives, environmental, producers, animal production policy

INTERSTATE TECHNOLOGY AND REGULATORY COUNCIL: REMOVING REGULATORY BARRIERS TO NEW TECHNOLOGIES

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Abstract
The Interstate Technology and Regulatory Council (ITRC) is a group of 46 states working together to share information on new technologies, problem contaminants, or other environmental concerns. The ITRC forms technical teams to work on issues such as phytoremediation, vapor intrusion, bioremediation, unexploded ordinances, and other areas important to states. Technical teams are state-lead and composed of a minimum of five states, industry, academia, public stakeholders, technology developers, and federal partners. Technical teams prepare documents and training for ITRC members and others to use to better understand the particular issue. Every ITRC document has corresponding two-hour internet training. To date, ITRC has trained more than 26,000 people. When appropriate, ITRC has also developed classroom training. With regard to agricultural technologies, ITRC has developed documents on phytotechnologies, constructed-treatment wetlands, and wetlands mitigation. We are particularly interested in confined animal feeding operations. This is a need that several states have brought to our attention. We hope that a conference like "The Future of Agriculture: Science, Stewardship, and Sustainability" will introduce ITRC to this audience and attract potential team members and funders.

Key words: technical teams, training, new technologies, problems contaminants, environmental concerns, animal production policy

APPLICATION OF MUNICIPAL BIOSOLIDS TO DRY-LAND WHEAT FIELDS - A MONITORING PROGRAM AT DEER TRAIL, CO (USA)

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Abstract

Metro Wastewater Reclamation District of Denver applies municipal biosolids to its farm properties near Deer Trail, Colo., as an agricultural soil amendment for dry-land crop production. Applying biosolids to agricultural fields could affect the quality of alluvial and bedrock aquifers, streambed sediments, soils, and crops. Soil quality could either be improved by biosolids applications through increased nutrients and organic matter, or be degraded through an overload of nutrients or metals. This increase of nutrients and/or metals could affect both the yield and quality of crops harvested. The USGS has designed and implemented a monitoring program to address concerns of the biosolids and the quality of the environment in the vicinity of the biosolids-application areas. This program (1999-2005) considers environmental quality issues for ground and surface water, soils, crops, and biosolids. Objectives of the monitoring program are to a) evaluate the effects of biosolids applications, land use, and natural processes on water, soils, and crops; and b) monitor biosolids for metals and radioactivity, and compare the measured concentrations with regulatory limits. Measurements of interest are As, Cd, Cu, PB, Hg, Mo, Ni, Se, Zn, plutonium (Pu 238, 239 and 240), and gross α and β activity.

Key words: biosolids, soils, wheat, trace elements, radioactivity, animal production policy

A CARBON-MINERALIZATION MODEL FOR PREDICTING PLANTING-TIME DELAY NEEDED TO AVOID PHYTOTOXICITY OF COMPOST-AMENDED SOIL

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Abstract

Mineralizable carbon plays an important role in phytotoxicity of compost-amended soil. Developing models of carbon mineralization upon amendment to soil, based on commonly made respiration rate measurements, could allow mineralizable carbon to be predicted and used for estimating phytotoxicity. In this study, first-order, second-order, and Monod kinetic models that take into consideration compost amendment rate, incubation time, and incubation temperature were developed to predict carbon mineralization when amended to soil. Carbon-mineralization experiments were performed with sandy loam and commercial potting soils amended with 0%, 5%, and 50% (v/v) food waste and green waste composts, and incubated at 20°C, 25°C, 30°C, 35°C, and 45°C. Models were validated using respiration data from carbon-mineralization experiments under a diurnal temperature regime from 20°C to 30°C, and compared for their ability to predict carbon mineralization as a function of time. Results showed that in most cases, first order had an equivalent or better fit than the other two models, although second order also had a good fit. Based on first-order model estimations, potential mineralizable carbon was found to be a good predictor of compost phytotoxicity in soil, suggesting it could be used by compost producers and growers in planting decisions to avoid phytotoxicity.

Key words: compost stability, kinetic modeling, decomposition, phytotoxicity, carbon mineralization, amendments

BIOLOGICAL ACTIVITY AND COMMUNITY STRUCTURE LEADING TO THERMAL RUNAWAY IN STORED AGRICULTURAL BIOMASS

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Abstract
Design of biomass storage systems is a critical factor facing lignocellulose-based industries. Improper storage conditions can result in decomposition and deterioration of biomass and self-heating to the point of ignition. Spontaneous combustion of biomass involves a series of processes, but generally biological activity is responsible for heating the biomass to a point that will sustain exothermic chemical reactions. We examined the influence of microbial activity on the self-heating of rice straw in storage in the temperature range of 18^{o}C to 55^{o}C; characterized the microbial kinetics of the system under different moisture conditions, temperature profiles, and oxygen concentrations; and characterized the active members of the microbial community using phospholipid fatty acid analysis (PLFA). Activity measured as peak respiration rate and cumulative CO_2 evolved and increased linearly between moisture contents of 30% and 100 % dry basis, and then leveled off between 100% and 250% dry basis. Activity also increased with increasing temperature between 18^{o}C and 35^{o}C. Activity began to decline at 45^{o}C and was not detected at 55^{o}C. PLFA biomarkers representing gram + microorganisms changed the most with storage time. Their behavior was well represented by a logistic growth model where the specific growth rate was expressed as a function of temperature.

Key words: rice straw, self-heating, kinetic modeling, community structure, spontaneous combustion, biomass

FARMING WITH BIOSOLIDS: CITY OF LOS ANGELES EXPERIENCE

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Abstract
When the city of Los Angeles bought 4,688 acres of land in Bakersfield, nobody knew that one day the city would be the one managing and operating it. Originally, the city executed a ground lease agreement for five years, with a five-year renewal option with the previous owner, to perform the farming operations of the land. When the lessee notified the city that it would not be able to further perform its obligations and continue farming as required by the lease, city staff looked for other options such as hiring a temporary farm operator who could continue the farm operation for a one-year period. The city executed four, 90-day agreements with R&G Fanucchi Farms to provide interim custom farming and farm management services at Green Acres Farm, while a new long-term farming contract was being worked on through the request-for-proposal process. Also, the city hired a farm manager to manage the daily farming operations. Different transitions of farming, coupled with application of biosolids as amendment, gave the city many experiences in dealing with biosolids' challenges. This paper/presentation will give insight on farming with biosolids, based on the experience of the city of Los Angeles.

Key words: biosolids, Los Angeles, farm management

DAIRY FARMING IMPACTS TO GROUNDWATER QUALITY

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Abstract
Many Western U.S. dairies are located in low-relief valleys and basins with vulnerable groundwater resources. We characterized and assessed shallow groundwater quality underneath dairies in a relatively vulnerable alluvial basin hydrogeologic region in the Central Valley of California. We discerned the impact from various individual sources and management practices within dairies. A multiple-tier monitoring approach was developed that included monitoring of nitrogen applications to fields and of nitrogen removal in crops, monitoring of nitrogen imports and exports to/from the farm, soil monitoring, shallow groundwater monitoring, tile-drainage monitoring, and production-well monitoring. The monitoring network spanned multiple dairy management units: manure water lagoons, corrals (feedlots), solid manure and silage storage areas, and manure-treated forage fields under various management practices. Water quality in soils and shallow groundwater was found to be widely impacted by salinity and nitrate, but highly variable between and within management units. Unlike at traditional (point source) contamination sites, a meaningful interpretation of such nonpoint source pollution data is only possible by explicitly considering the various spatial scales affiliated with monitoring measurements, nitrogen source management, regulatory control, and groundwater extraction (beneficial use). We provide an interpretation of the observed groundwater quality data (primarily nitrate) that is meaningful at the field scale (subject to individual management decisions), the farm scale (considered to be a regulatory and planning unit), and the regional scale (considered to be a planning unit). At the local scale, a strong linkage was found between field nitrogen balance and shallow groundwater quality. Regional-scale modeling suggested that under current management conditions, groundwater degradation with nitrate will reach regional levels that may be as much as half an order of magnitude above the drinking water limit. Recent trends in domestic well water quality support such an assessment.

Key words: groundwater quality, animal farming, dairy, nonpoint source pollution, nutrient management

IMPACT OF IMPROVED NUTRIENT MANAGEMENT PRACTICES ON SHALLOW GROUNDWATER QUALITY UNDER DAIRIES

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Abstract

Dairy is the leading agricultural industry in California. Many of these dairies are located on light soils with shallow groundwater, and degradation of groundwater quality as a result of misapplication of dairy wastewater has been documented. This paper reports on a 10-year project to determine the impact of improved nutrient management practices on groundwater quality under dairies. Nutrient application practices involved using a synchronized-rate, nutrient application technique where targeted amounts of dairy lagoon nutrients were injected into irrigation water multiple times during the season, at rates and timings that closely anticipated crop nitrogen requirements. Early years of the study demonstrated that careful management of manure nutrients can dramatically improve shallow groundwater quality. However, in carrying this study forward for several more years, groundwater nitrate concentrations have risen considerably from the initial lows. This is attributed to higher concentrations of organic-form nitrogen present in the nutrient water. Yields have also suffered, despite excess total nitrogen being applied. New methods of managing organic nitrogen, especially sludge, need to be developed if groundwater quality under diary land application fields is to be protected.

Key words: dairy waste, nutrient management, groundwater, water quality

SATURATED-ZONE DENITRIFICATION AT CALIFORNIA DAIRIES

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Abstract
Denitrification can effectively mitigate the problem of high-nitrate concentrations in groundwater under dairy operations by reducing nitrate to N_2 gas at sites where biogeochemical conditions are favorable. We present results from field studies at central California dairies that document the occurrence of saturated-zone denitrification in shallow groundwater using biomolecular indicators, stable isotope compositions of nitrate, and measurements of dissolved excess N_2 gas. Excess N_2 concentrations provide a measure of the extent to which nitrate in groundwater has been partially or completely denitrified. Abundant excess N_2 and young $^3H/^3He$-apparent groundwater ages indicate high denitrification rates near manure lagoons where multiple lines of evidence indicate seepage of lagoon water into the groundwater system. Natural tracers of lagoon water include high chloride and dissolved organic carbon concentrations, distinctive trace organic compounds, and high groundwater $\delta^{18}O$ values (relative to other recharge sources). Proximal to the lagoons, NH_4^+ may be present in groundwater but is strongly adsorbed on to sediment particles. Bubble formation in the lagoons causes the exsolution of other gases (N_2, Ar, Ne, He, etc.), which partition into the gas phase and strip the lagoon water of its dissolved gas load, providing a unique tracer of lagoon seepage in groundwater.

Key words: dairy, nitrate, denitrification, lagoon, isotopes

DEVELOPMENT AND INTEGRATION OF A NATIONAL FEED MANAGEMENT EDUCATION PROGRAM AND ASSESSMENT TOOLS FOR COMPREHENSIVE NUTRIENT MANAGEMENT PLANNING

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Abstract
In 2003, the U.S. Environmental Protection Agency (EPA) released new guidelines for concentrated animal feeding operations (CAFO), requiring permitted CAFOs to develop a nutrient management plan (NMP). A USDA Natural Resources Conservation Service (NRCS) comprehensive nutrient management plan (CNMP) will satisfy requirements of an NMP. One core element of the CNMP is feed management. In 2005, a national feed management education project was funded by the NRCS Conservation Innovation Grant (CIG) program. The project will develop, test, and implement a national feed management education program and assessment tools. The goal of the project is to increase the understanding of feed management to agricultural professionals, with an emphasis on environmental and financial sustainability of livestock and poultry operations. A team consisting of consulting animal nutritionists, technical service providers (TSP), extension specialists, and research scientists will accomplish the following program objectives: 1) develop and evaluate tools for assessing the impacts of feed management practices on whole-farm nutrient balance to be used by animal nutritionists, NRCS staff, and TSP; 2) develop a feed management chapter for the NRCS Agricultural Waste Management Field Handbook; and 3) develop and implement an education program targeting integration of feed management into a CNMP.

Key words: feed management, nutrient management, environment

SUSTAINABLE DEVELOPMENT OF BIOMASS IN CALIFORNIA

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Abstract
California annually produces close to 100 million tons of biomass as agricultural and forest residues and urban wastes. The sustainable resource value of these for bioenergy and biobased products remains below full potential. Recent state initiatives and mandates calling for reductions in petroleum use and greenhouse gas emissions, and a greater share of electricity from renewable resources provide opportunities for further biomass development. This presentation outlines technical, environmental, and economic needs and benefits associated with increasing use of biomass resources, and summarizes recommendations for development.

Key words: biomass, residue, wastes, renewable sources, energy solutions

DEVELOPMENT OF A BIO-BASED MOTOR OIL AND THE IMPACT ON ENGINE PERFORMANCE IN GASOLINE-POWERED VEHICLES

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Abstract

Bio-based motor oils have been found to significantly reduce tailpipe emissions while reducing fuel consumption in automotive engines. Utilizing high-oleic, canola-based motor oils, engine tests were conducted on 52 vehicles from the general fleet of the United States Postal fleet in Michigan. Further studies were done with new E-85 vehicles purchased by the Postal Service. Data on emissions show a dramatic decrease in tailpipe emissions from changing the motor oil. The vehicles used were fueled by conventional petroleum gasoline. All tests were done at a certified EPA test station in Ohio using protocols used by the automotive industry in setting emissions data. Emissions results show a reduction of nitrous oxides of 80% from the petroleum control. Other reductions included hydrocarbons, volatiles, and carbon monoxide. All emissions tested were significantly reduced when compared to petroleum-based motor oils. Friction reductions had been noted as reduced-wear metals in engine tests. Increased engine performances were observed in multiple vehicles via smoother operating and increased horsepower. In bench tests using an extended four-ball wear analysis, friction coefficients were reduced to half those of either synthetic or conventional motor oils. Such reductions should increase base horsepower by 2-4% and increase fuel economy by similar amounts. Field trials have verified the motor oils do increase fuel economy by the expected amounts. Biodegradability and toxicity analyses show the canola-based motor oils remain nontoxic and meet federal biodegradability standards after use. Trials using marine toxicity tests as well as landfill toxicity analyses show the used motor oils are approximately 330,000 times less toxic than equivalent petroleum crude oil. Biodegradability was conducted using the modified Sturm protocol. The canola-based motor oils easily met biodegradability standards set for lubricants.

Key words: bio-based motor oils, emissions, increased horsepower, energy solutions

EMISSION REDUCTIONS FROM AGRICULTURAL SOURCES: THE ROLE OF STATE-BASED INCENTIVE FUNDING IN CALIFORNIA FOR AIR QUALITY IMPROVEMENTS

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Abstract
The agriculture industry contributes greatly to the economy and identity of California, as well as contributing to California's unique air quality challenges. As agricultural sources become increasingly subject to air quality regulations, incentive programs can help obtain early emission reductions while reducing costs to the regulated community. The Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program) is a grant program that funds the incremental cost of cleaner-than-required engines and equipment to help California meet its clean air goals. The Carl Moyer Program has successfully reduced air emissions from thousands of pieces of agricultural equipment such as diesel agricultural pump engines. Recent legislative changes have expanded the Carl Moyer Program, and additional agricultural projects may qualify for funding in the future. The Carl Moyer Program may serve as a model for other agricultural incentive programs.

Key words: California, incentives, regulations, air quality, energy solutions

EMISSION REDUCTIONS FROM A UTILITY INCENTIVE PROGRAM TO CONVERT DIESEL-FIRED AGRICULTURAL PUMPS TO ELECTRIC

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Abstract

This paper summarizes the preliminary emission reductions resulting from Pacific Gas and Electric Company's (PG&E) AG-ICE Conversion Incentive Program. The AG-ICE Program, implemented August 1, 2005, offers various incentives to agricultural customers who convert internal combustion-powered irrigation pumps to electric. As part of the tariff, the agricultural customer agrees to assign the associated emission reductions to PG&E. This paper discusses the emission reductions (both criteria pollutants and greenhouse gases) to date, the calculation methodology, and future steps for potential emission-reduction certification by the California Climate Registry.

Key Words: agricultural criteria, greenhouse gas emission reductions

Introduction

PG&E Background

Pacific Gas and Electric Company (PG&E), incorporated in 1905, is one of the largest investor-owned utilities in the country. With a workforce of 19,800 men and women, PG&E delivers electric and natural gas service to approximately 15 million people (1 in 20 Americans). PG&E's service area encompasses 70,000 square miles in northern and central California and consists of more than 146,744 circuit miles of electric lines and 46,832 miles of natural gas pipelines.

PG&E recognizes that the way it produces and delivers products and services to its customers can have a direct impact on the environment. PG&E also believes that a healthy environment is necessary for the well being and vitality of its customers, its employees, the communities it serves, and society at large.

PG&E's commitment to environmental excellence is rooted in the company's environmental policy, which, in part, states the following:

> *PG&E Corporation is committed to being an environmental leader by providing safe, economical, and reliable products and services in a responsible and environmentally sensitive manner.*

In particular, PG&E is committed to leading by example when it comes to climate change. This means more than just minimizing greenhouse gas emissions from its operations. It also means helping to establish rigorous accounting and reporting protocols for greenhouse gas emissions, supporting policies that would limit greenhouse gases, and being transparent about what the company is doing on climate change and its strategies going forward.

Air Quality in California's Central Valley

California's San Joaquin and Sacramento valleys, collectively known as the Central Valley, are subjected to heavy amounts of air pollutants, ranking with the Los Angeles Basin as one of the most polluted regions in the nation. Air pollution in the Central Valley persistently exceeds national ambient air quality standards (NAAQS).

According to the San Joaquin Valley Air Pollution Control District's Proposed 2002 to 2005 Rate of Progress Plan, in the presence of sunlight, oxides of nitrogen (NO_x) and reactive organic gasses (ROG) form low-level ozone. The document goes on to state the following:

> Ozone is a major component of "smog." In humans, ozone can irritate and inflame the respiratory tract, particularly during heavy physical activity, resulting in heavy coughing, throat irritation, and breathing difficulty. Ozone can also adversely affect the body's immune system, hence, lowering its resistance to infections, allergens, and pneumonia. At lower concentrations, ozone decreases the flow of oxygen in the lungs and increases resistance to air passages in lung tissue. Resulting symptoms range from coughs and chest discomfort to headaches and eye irritation. High concentrations of ozone can cause severe damage to lung tissue, and intensify heart and lung disease. Groups that are highly susceptible to the effects of ozone include children, the elderly, persons engaged in physical activity, and persons suffering from respiratory ailments and cardiovascular disease. Ozone also damages vegetation and agricultural crops by interfering with the photosynthesis

process. Crop yields of grapes, cotton, oranges, alfalfa, and tomatoes have been shown to be reduced by as much as 20 percent. The ARB estimates that the SJVAB's [San Joaquin Valley Air Basin] agricultural crop losses exceed $150 million due to exposure to ozone. According to the National Park Service, up to half the Ponderosa and Jeffery Pine in the Sierra Nevada Mountains show ozone injury (San Joaquin Valley, 2002).

According to the California Air Resources Board (CARB), agricultural sources contribute 26 percent of the smog-forming emissions in the San Joaquin Valley (San Joaquin Valley, 2002) CARB estimates that there are more than 5,700 stationary (Senate Bill 700)[1] diesel-powered pumps used for irrigation in the Central Valley, which are significant contributors to agriculture's air quality impact. In part because of this impact, the Sacramento and San Joaquin valleys are currently classified as federal air quality non-attainment areas for ozone, which could result in a reduction of federal transportation funding for California.

Hot summer days when ozone levels are highest are also days when diesel engines are used to operate irrigation pumps. CARB estimates that more than three million people in the California Central Valley breathe unhealthy air one day out of three in the summer because of excessive ozone levels.

During the 2003 summer, CARB estimated that diesel-powered irrigation in the Central Valley emitted 33 tons per day of NO_x, which accounted for nearly 23 percent of the total NO_x emissions from stationary fuel-combustion sources in the region. In addition, CARB estimated that diesel pump emissions represent about 31 percent of ROG from stationary fuel-combustion sources in the Central Valley.

The region suffers from unhealthy air quality in the winter months as well, largely due to particulate-matter (PM) emissions. CARB estimates that during 2003, 17 percent of PM emissions from stationary fuel-combustion sources in the region were caused by diesel-powered irrigation pumps. It is estimated that PM accounts for 70 percent of the known

[1] For purposes of AG-ICE, stationary engines are internal combustion (IC) engines (either permanent or portable) that are designed to remain in one location during operation. Portable engines are those that can be carried or moved from one location to another, but remain in place while in operation. Engines that can move on their own power (such as truck engines) are considered "mobile" engines.

cancer risk that is attributable to exposure to toxic air pollutants in California (Witherspoon, 2003).

Potential Solution to Diesel Pump Emissions

In response to environmental and health effects of these stationary agricultural pumps in California's Central Valley, Pacific Gas and Electric Company (PG&E), with input from agricultural customers (as represented by Agricultural Energy Consumers Association), the San Joaquin Valley Air Pollution Control District, plus other partners successfully developed and implemented the Agricultural Internal Combustion Engine Conversion Incentive Program (AG-ICE). The program assists agricultural customers in converting from diesel agricultural water pumps to electrical pumps by providing a reduced electric rate and enhanced line-extension allowance. The incentive program, which was approved by the California Public Utilities Commission (CPUC) on June 16, 2005, includes numerous benefits to the customer, the environment, and PG&E.

The AG-ICE program provides up to $32,000 for an electrical line extension in addition to what customers are normally provided. Customers enrolled in the program receive electricity rates for their pumps that are approximately 20% below those for customers not enrolled. This rate is contracted in place until 2015, with a yearly increase of 1.5%. Additionally, customers may apply for funding through CARB's Carl Moyer program, which gives millions of dollars annually for emission-reduction projects not required by regulation.

As of July 11, 2006, 1321 applications have been received, and 231 engines have already been converted to electric. By the time enrollment is closed in July 31, 2007, PG&E expects 2100 applications.

The program has not only resulted in considerable emission reductions, but has also enhanced PG&E's reputation with regulatory agencies and environmental groups. Participating customers are reaping the benefits of stable, reliable electricity pricing; timely installation of electrical hook-ups; and the avoidance of upcoming, expensive, burdensome diesel-engine regulations.

The program's success has been the result of a collaborative effort among PG&E, the Agricultural Energy Consumers Association, the Central Valley's Air Districts (Sacramento and San Joaquin), California Air Resources Board (CARB), the U.S. Environmental Protection Agency – Region IX, Natural Resources Defense Council, the California Farm Bureau Federation, and others.

Emission Reductions

Based on the 1321 program applications received through July 11, 2006, the program is estimated to eliminate more than 18,000 tons of NO_x, 1300 tons of PM, and 680,000 tons of CO_2 over the life of the program (until 2015). This CO_2 reduction is approximately equivalent to the emissions from 2.1 billion miles driven[2]. If the anticipated 2100 applications are received before July 31, 2007, estimated total reductions will be more than 29,000 tons of NO_x, more than 2000 tons PM, and more than 1,080,000 tons of CO_2. Additional information on emission-reduction calculations can be found in Appendix A.

Once the two-year application window closes, PG&E plans to calculate the emissions on a per-engine basis. As part of PG&E's agreement with the San Joaquin Valley Air Pollution Control District and the Sacramento Metropolitan Air Quality Management District, criteria pollutant (NO_x and PM) reductions will be assigned to the air districts, and the greenhouse gas (CO_2) reductions will be assigned to PG&E. Simultaneously, PG&E will pursue third-party verification of the CO_2 emission reductions achieved through this program for verification by the California Climate Action Registry.

Appendix A: Emission-Reduction Calculations

Anticipated particulate matter (PM), oxides of nitrogen (NO_x), and carbon dioxide (CO_2) emission reductions are based on NO_x reductions from 231 engines that have already been converted to electrical pumps. According to data provided by the San Joaquin Valley Air Pollution Control District, an estimated 3213 tons of NO_x emissions from these pumps will be prevented due to this program. Estimates of PM and CO_2 reductions for the 1261 program applications received as of July 11, 2006, are based on estimated NO_x reductions from these initial 231 conversions and the emission factors below taken from the Environmental Protection Agency's AP-42.

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[2] Based on: 30mpg and 19 pounds of CO_2 per gallon of gasoline

Oxides of Nitrogen (NO_x)	Particulate Matter (PM)	Carbon Dioxide (CO_2)
3.1×10^{-2} lb/hp-hr	2.20×10^{-3} lb/hp-hr	1.15 lb/hp-hr

Based on the ratios of PM and CO_2 emissions to NO_x emissions and the estimated NO_x reductions from the initial 231 conversions, it was calculated that the following emissions are eliminated from each converted engine:

NO_x: 14 tons

PM: 1 ton

CO_2: 516 tons

Thus, if all 1261 applicant engines are converted, over the life of the program (until 2015), the following estimated emissions will be eliminated:

NO_x: 17, 537 tons

PM: 1245 tons

CO_2: 650,577 tons

And if the anticipated 2100 applications are received and all engines are converted, over the life of the program, the following estimated emissions will be eliminated:

NO_x: >29,000 tons

PM: >2000 tons

CO_2: 1,080,000 tons

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MULTI-FACETED CONSIDERATIONS FOR SUSTAINABLE PHYTOREMEDIATION UNDER FIELD CONDITIONS

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Abstract

Interest in selenium pollution and remediation technology has escalated during the past two decades. A major selenium controversy in the 1980s emerged in California when the general public and scientific community became aware of selenium's potential as an environmental contaminant. After extensive research on several strategies to reduce loads of mobile Se from entering the agricultural ecosystem, a plant-based technology defined as phytoremediation received increasing recognition as a low-cost environmentally friendly approach for managing soluble Se in the soil and water environment via accumulation and volatilization. Successful long-term field remediation of Se by plants is, however, dependent upon acceptance and widespread use by growers, who are also concerned about potential commercial value from using the plant-based technology. In this regard, new phyto-products were developed from plants used in the field phytoremediation of Se in central California. These included Se-enriched broccoli, Se animal feedstuff, organic fertilizer, and canola oil for use as a blend with diesel fuel in the production of biofuel. This oral presentation discusses long-term field experience using phytoremediation, as well as production of new bioproducts from a contaminant.

Key words: phytoremediation, selenium, phytoproducts, natural systems remediation

BIOREMEDIATION OF PESTICIDES AT THE BORELLO PROPERTY

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Abstract
Many pesticides such as toxaphene and dieldrin were specifically developed to persist in the environment, making them difficult to remediate using standard technologies. Naturally occurring bacteria in the soil can be damaged when pesticides are used. When this soil amendment is added, it helps existing bacteria in the soil to metabolize pesticides into salt, carbon dioxide, and water. The presentation will discuss the nature of the contamination at the Borello Property, results of the treatability study, how this project allowed for significant savings in cleanup costs, and other potential applications of this technology.

Key words: land restoration, bioremediation, pesticides, toxaphene, dieldrin, natural systems remediation

IN SITU REMEDIES FOR AGRICULTURAL CHEMICALS IN GROUNDWATER: CASE STUDIES AND FUTURE PROMISE

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Abstract
Remediation of agricultural chemicals in groundwater is an area of increasing interest as land development encroaches upon agricultural areas. Presence of persistent and recalcitrant organic compounds in soil and groundwater, including the pesticides ethylene dibromide, 1,2-dichloropropane, and 1,2,3-trichloropropane, present unique cleanup challenges at many agricultural sites. This presentation provides an overview of groundwater remediation at agricultural sites, based on more than 20 environmental investigation and remediation projects throughout California and Oregon. We use case studies to illustrate occurrence and distribution of agricultural chemicals of interest in groundwater, including nitrate; 1,2-dichloropropane and 1,2,3-trichloropropane; factors in selecting an effective remediation strategy for agricultural chemicals in groundwater, including complex groundwater geochemistry and contaminant mixtures, site hydrogeology, neighboring land uses, site logistics and infrastructure, regulatory concerns, etc.; and results of in situ remediation technologies evaluated in the lab and applied in the field, including bioremediation and abiotic treatments. We close with a discussion of future promise for existing and new in situ technologies.

Key words: 1,2-dichloropropane, 1,2,3-trichloropropane, in situ groundwater remediation, natural systems remediation

COST COMPARISONS OF PHYTOTECHNOLOGIES TO OTHER REMEDIAL APPROACHES

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Abstract
When developing cleanup strategies, site owners are typically propositioned with multiple options. In many cases, these options are presented showing substantial, if not fantastical, economic benefits. The same can be said for technology development projects. In order to gain acceptance from the site owner, the economic benefits need to be presented in terms of the time value of money. For phytotechnologies, the savings is partially from reduced capital, but mainly from lower O&M requirements once established. However, the long-term nature of phytotechnologies may partially offset the perceived savings. To show the value of each option on a common basis, the net present cost (NPC) should be provided rather than the total life cycle cost. In addition, each option depends on other factors including regulatory process, feasibility, sustainability, reuse/restoration, stakeholder acceptance, etc. An economic concept used with NPC calculations to show realistic value-added estimates is the weighted probability of outcomes. The analysis incorporates these "less tangible" factors by estimating the probability of outcomes for each option. For each option, these probabilities are estimated to establish a probability-weighted NPC to remediate the site. Comparing this consolidated value to the final solution NPC provides a more representative value-added estimate.

Key words: phytotechnologies, economics, net present cost, value added, site owners, natural systems remediation

IN SITU BIODENITRIFICATION OF GROUNDWATER FOR A SMALL RURAL COMMUNITY – THE VEGUITA PROJECT

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Abstract
New Mexico Governor Richardson's Water Innovation Fund provided an opportunity to deploy enhanced in situ bioremediation (EISB) technology to demonstrate biodenitrification of groundwater in a rural community located on the site of a farm where excessive application of fertilizer had occurred. During aquifer characterization, groundwater monitoring and a pumping test identified a productive aquifer, 60 to 110 feet deep, with 10 times the MCL of 10 mgl nitrate (nitrogen). This level of nitrate in the community's only drinking water source poses a severe health hazard, especially to infants. The lateral extent of contamination could not be determined, so a wellhead protection approach was used to design a demonstration in situ treatment system consisting of one pumping well surrounded by eight injection wells. Molasses was injected at 4-8 g/L at a rate of 30 gpm before pumping began. The injected molasses was left undisturbed for 11 days to form a bio-treatment ring. After pumping began, nitrate concentrations were monitored and additional molasses was injected as needed to maintain the bio-treatment ring and achieve denitrification. This project provided valuable experience in design and operation of a denitrification system for small rural communities where the drinking water has been degraded by agricultural practices.

Key words: nitrate, denitrification, bioremediation, wellhead protection, bio-treatment

HOW THE ENVIRONMENTAL KNOWLEDGE AND ASSESSMENT TOOL CAN ASSIST IN ENVIRONMENTAL ANALYSES OF AGRICULTURAL CHEMICALS

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Abstract
The Environmental Knowledge and Assessment Tool (EKAT: www.ekat-tool.com) is a Web-based project management and decision-support tool to identify, research, and evaluate environmental and pollution prevention options, and safety-related issues for materials used in products and systems. EKAT contains information on technical and regulatory requirements, and serves as a resource center with links to references, tools, and databases to assist in research efforts and minimize unintentional safety and environmental effects associated with product development or use. Features include project management and organizational capability, collaboration within project teams or the EKAT community, and communication through threaded discussions; all of which help facilitate discussions between agricultural and environmental specialists. EKAT serves as a preliminary environmental screening tool for regulatory requirements and potential issues of concern that may affect the agricultural community. The user may quickly screen chemicals against lists of federally regulated chemicals, get help estimating emissions from equipment or processes using the emissions calculator based on Environmental Protection Agency (EPA)- approved emission factors, or review information resource documents (IRs) and research guides which provide additional environmental information and resources in a user-friendly format.

Key words: environment, regulations, program, agriculture

Introduction

One of the goals of the Environmental Knowledge and Assessment Tool (EKAT) is to find a way to organize the immense quantity of environmental information available electronically in order to facilitate finding relevant information quickly and easily. EKAT contains components relevant to both environmental professionals and those with little environmental knowledge or background.

EKAT is a Web-based research, project management, decision-support tool created to identify, research, and evaluate environmental and safety-related issues for products and systems. The program presents information on technical and regulatory requirements and serves as a preliminary environmental screening tool for potential issues of concern. EKAT also serves as a resource center with links to other references, tools, and databases to assist in research efforts and minimize unintentional safety and environmental effects by utilizing publicly available environmental information and software.

Information available in EKAT has been reviewed by environmental professionals and is considered to be from reliable sources. Databases, documents, and other information found in EKAT have been extensively reviewed and are considered up-to-date for each new version of EKAT.

EKAT is organized as both an active project management and review system where environmental issues associated with a material or activity can be evaluated in a semi-automated process, and as a resource center where one would be able to conduct additional research on his or her own and quickly locate specific tools and other references to assist in evaluation efforts. Users can generate supporting documentation using EKAT tools to generate information or by uploading documents from outside EKAT into their project files.

Many elements of EKAT are useful to local and state governments, industry and business personnel, researchers, educators and assistance providers, and environmental consultants. EKAT consolidates a wealth of data, making critical information readily accessible and easy to find. Environmental professionals can use EKAT as a resource to screen chemicals against regulatory and safety and health requirements, as well as to draft appropriate documentation, track risk management, or estimate life-cycle impacts.

Program Applications

EKAT development is funded by the federal government and managed by the Marine Corps Systems Command (MARCORSYSCOM), and hence the primary focus of development is to assist MARCORSYSCOM with managing environmental issues for their projects and programs. However, while the current primary user group is the U.S. Marine Corps, with their blessing, EKAT is being developed with sufficient flexibility to be useful to others, including members of the agricultural community.

A great deal of environmental and health and safety information is available, and the World Wide Web makes accessing such information easier and faster. One of the goals of EKAT is to make use of existing tools and Web sites and avoid “reinventing the wheel.” Some information is housed in EKAT, while other information is linked to external sites, allowing the user to have the most up-to-date information directly from the source.

One of the most beneficial aspects of EKAT is its ability to serve as a preliminary environmental screening tool for regulatory requirements and other potential issues of concern. When you use EKAT, you may –

- perform screenings of chemicals used in a product or pesticide, highlighting environmental and safety compliance issues for materials in your system;
- use the tool for estimating chemical concentrations in air (TECCA) to estimate the average concentration in well-mixed air in a room where a volatile liquid chemical is released or spilled;
- use the emissions calculator (EmisCalc) to estimate air emissions, which may impact the need for a state air permit; and
- use the tool for reduction and assessment of chemical and other environmental impacts (TRACI), developed by the U.S. EPA and adapted to EKAT, to evaluate the environmental impact of chemical emissions to air or water over a product's lifecycle;
- view information resources or report guidance documents, which provide additional topic information and links to resources for assistance with compliance requirements, environmental or safety and health issues, or other specific topics.

The layout of EKAT is such that it is divided into eight key areas accessible from the home page: Tools, Research, Public Forum, About, Announcements/Search/First Time User's Guide, Wizard, Tutorials, and My Projects. The EKAT home page is shown in Figure 1.

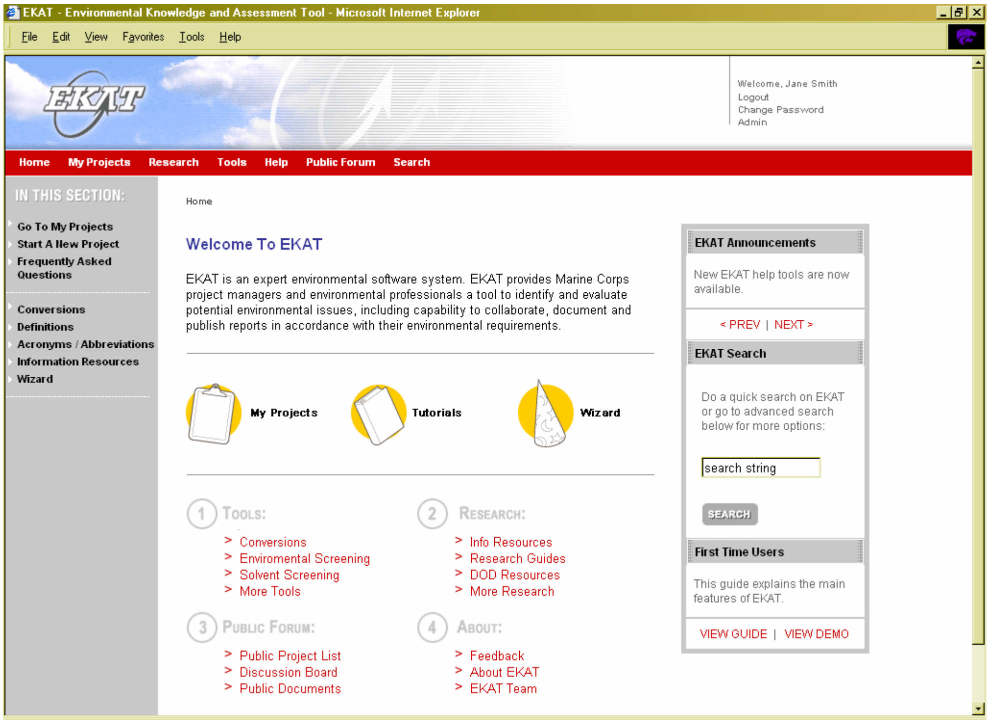

Figure 1. The Environmental Knowledge and Assessment Tool home page.

Tools – EKAT contains specially designed tools and links to external tools, to assist the user in evaluating environmental and health and safety issues. These include a units conversion tool to allow for easy conversion between different units of measure, an "environmental screening" feature to quickly screen a single chemical for federal regulatory information and other safety or health issues without setting up a project, and easy access to particularly useful environmental tools created and maintained outside of EKAT.

For example, if an EKAT user was doing an analysis of a particular pesticide, and he or she discovers it contains atrazine and next wants to examine the toxicological issues associated with these compounds, one place to look in EKAT for information would be under the Tools section. There, the person would find a link to TOXNET, a cluster of databases on toxicology, hazardous chemicals, and related areas maintained by the U.S. National Library of Medicine. By entering a subject matter inquiry, he or she can obtain the information sought. The TOXNET search result page is shown in Figure 2.

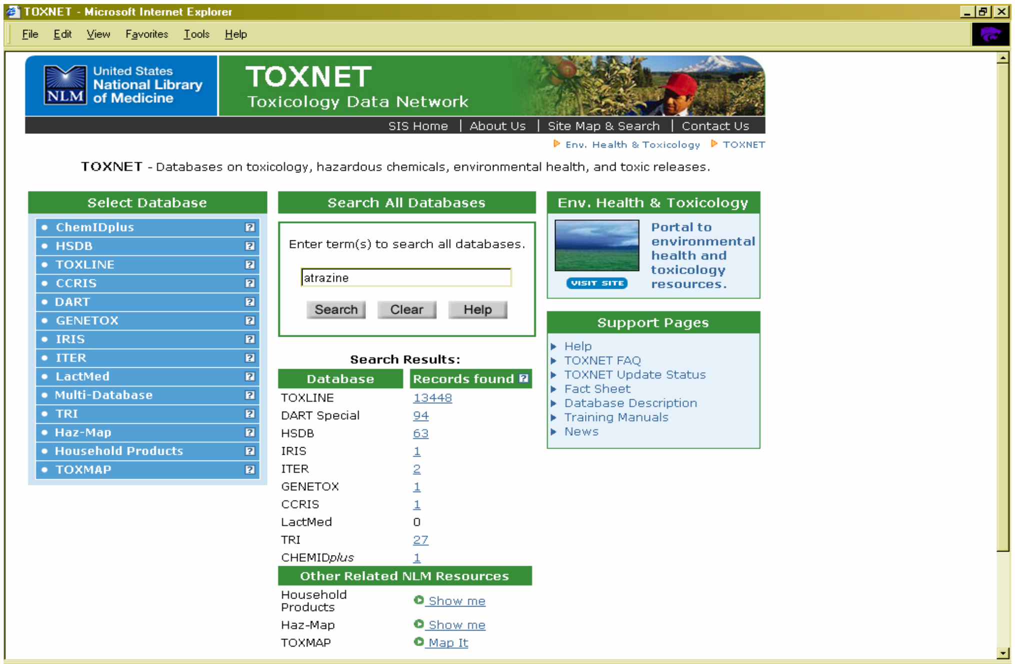

Figure 2. TOXNET result page for atrazine.

Research – The "Research" section provides quick access to environmental resources in order to research chemical-specific information, regulatory or safety and health topics, and pollution prevention alternatives. This section includes links to information resource (IR) documents and research guides on physical and chemical properties, hazardous waste identification and management, particulates, and toxicology.

IRs contain a summary about a particular topic that includes an overview of the topic and links to Web sites with additional information. Seventy different IR topics are organized under the categories of environmental compliance, NEPA compliance, safety and health, hazardous materials, explosives, pollution prevention, and international regulations and treaties. A sample IR page is shown in Figure 3.

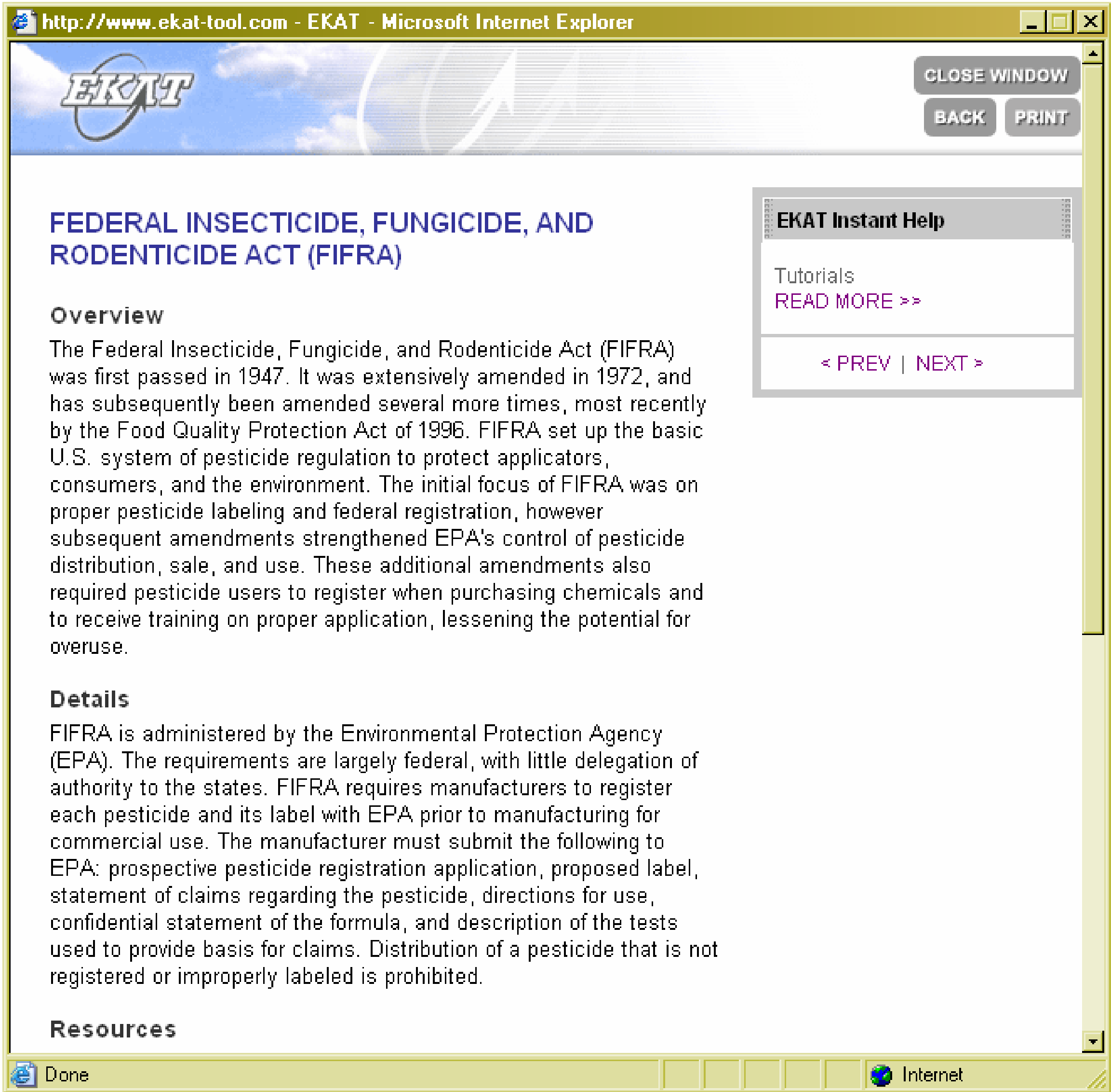

Figure 3. Sample information resource (IR) page of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

In the example above, if an EKAT user wished to learn more about the Federal Insecticide, Fungicide, and Rodenticide Act, by reviewing the IR, he or she could get an overview of the purpose of the regulation, further details for specific information, and links to external sites where actual regulatory lists or agency directives are present.

In addition to the numerous information resource documents, EKAT contains four detailed guides, as mentioned above. Research guides go into greater detail on their respective subjects: physical and chemical properties, hazardous waste management, toxicology, and particulates.

If one were interested in finding information on the physical characteristics of DDT (1,1'-(2,2,2-trichloroethylidene)bis 4-chloro-benzene), for example, the first thing to do would be to review the Research Guide on Physical and Chemical Properties (Figure 4).

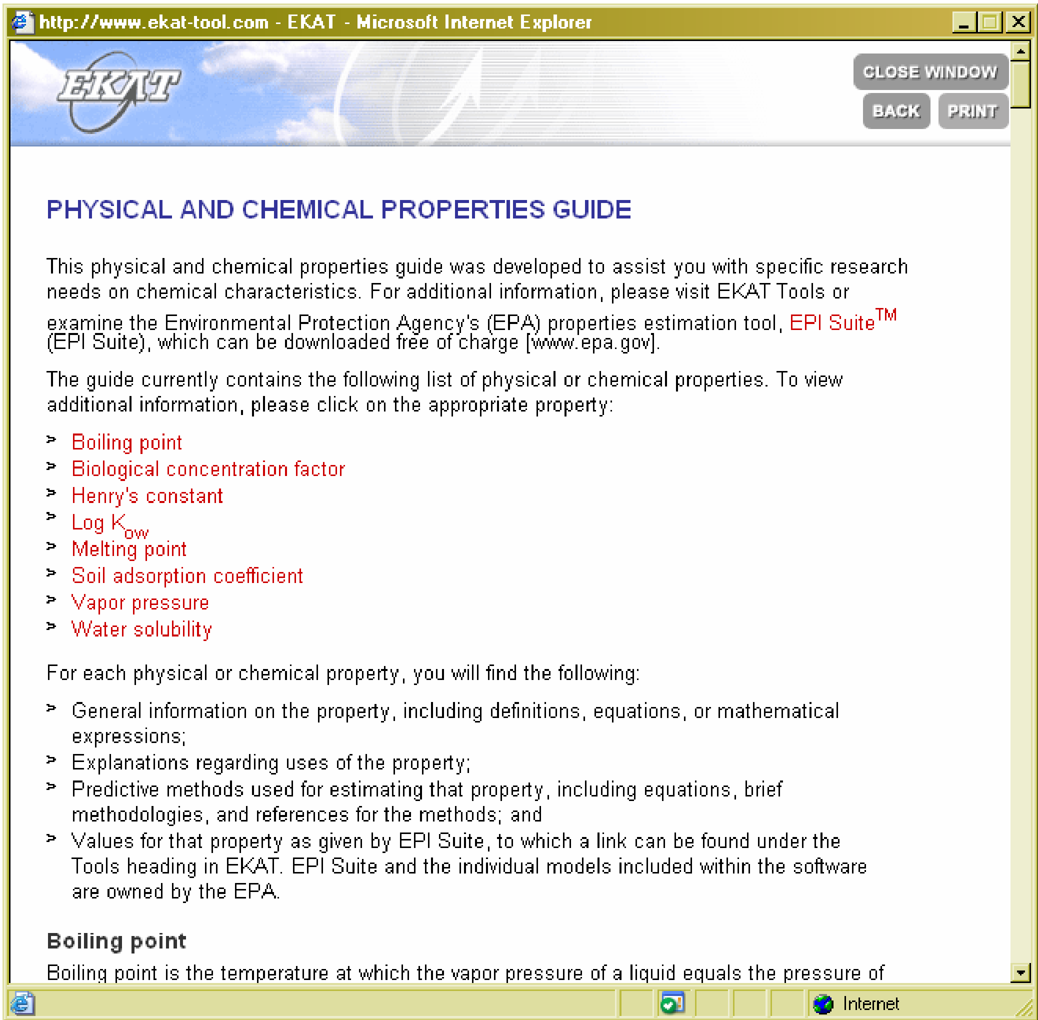

Figure 4. Physical and chemical properties research guide.

From the research guide, the EKAT user can assess the link to EPISuite™ where he or she could then utilize the EPA program to find the information they were looking for. EPI Suite™ and the individual models included within the software are owned by the U.S. Environmental Protection Agency, and individuals may download and use the software on their personal and business computers. EPISuite™ results regarding physical properties of the chemical compound DDT (CAS 50-29-3) are shown in Figure 5.

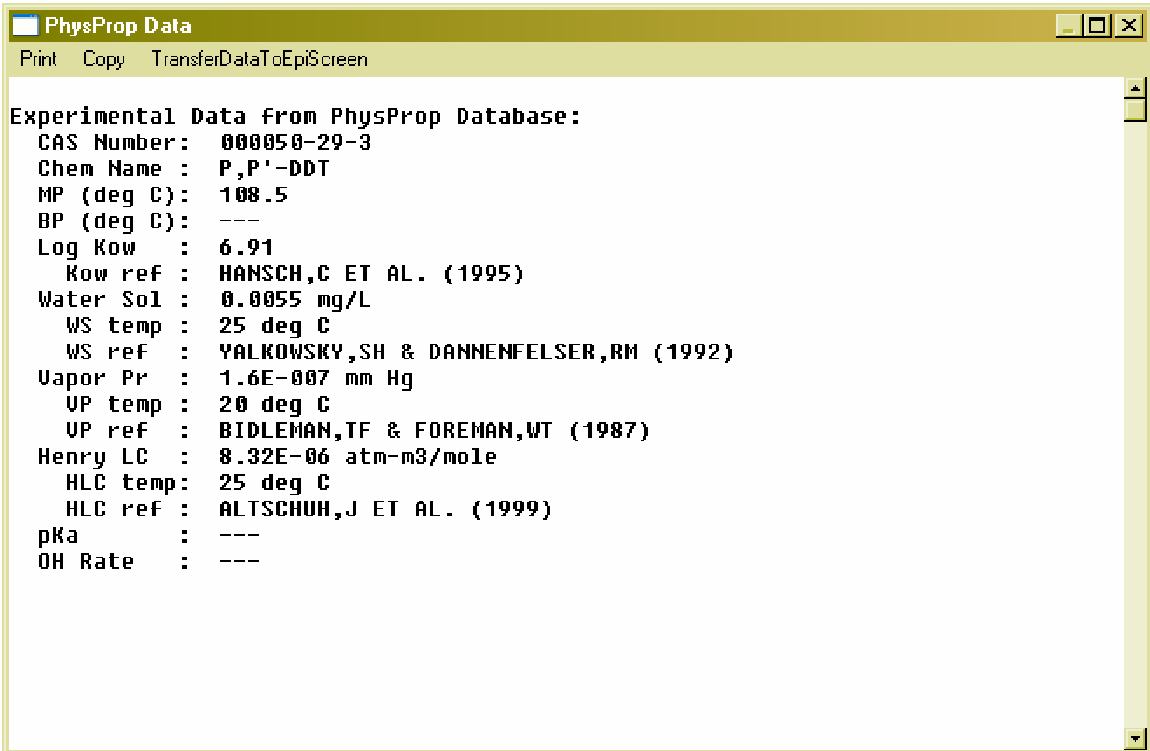

Figure 5. Output from EPISuite™ for DDT.

Other useful links under the "Research" section include pages explaining how chemical names for the same substance (synonyms) and Chemical Abstract Services (CAS) registry numbers may be found; how material safety data sheet (MSDS) information is organized; a link to the U.S. National Library of Medicine TOXNET Web site, a cluster of databases on toxicology, hazardous chemicals, and related areas; and a link to a periodic table and associated information provided by Los Alamos National Laboratory.

Public Forum – This feature allows EKAT users to share information and collaborate with other project team members or the EKAT community through the Public Project List, Discussion Board, or by posting useful information in Public Documents. The shared information is accessible to anyone using EKAT.

The "Public Project List" is a list of all projects chosen to be published by the project owner. Title of the project, date the project was created, and an e-mail contact of the owner are displayed. The project owner can be contacted for additional information about a particular project.

On the Discussion Board, an EKAT user can post a question to the EKAT community regarding a particular issue or problem he or she is having difficulty with, as shown in the following example page.

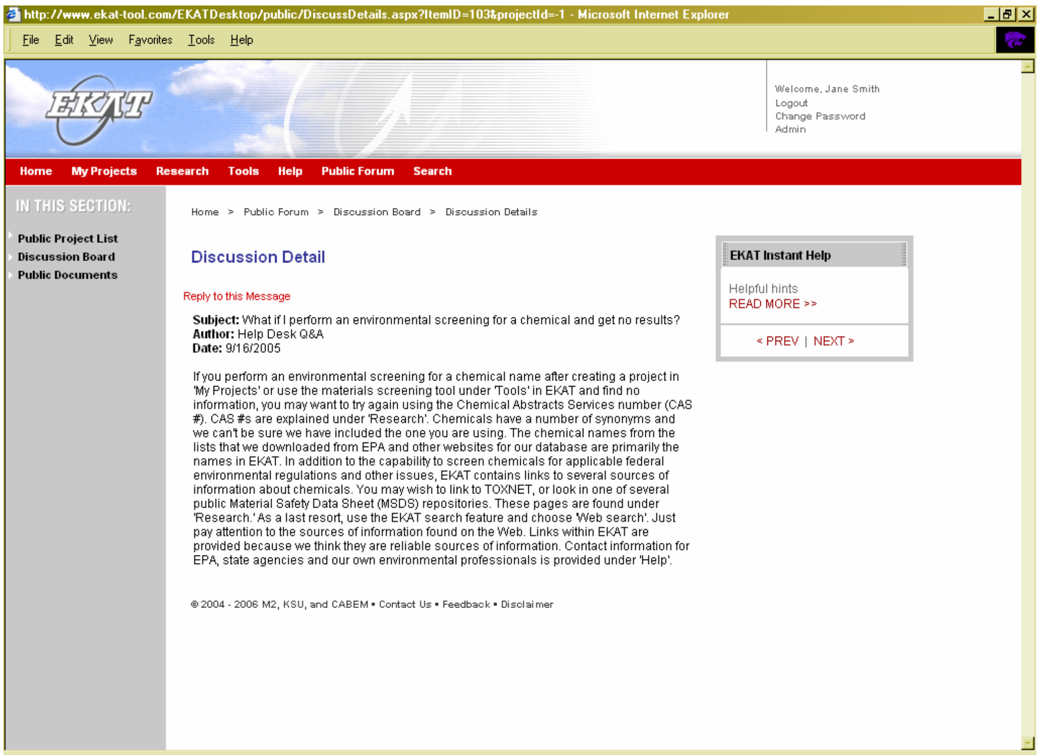

Figure 6. Feedback on the Discussion Board regarding environmental screenings. The environmental screening tool is discussed later in the article.

About – Users can find out more information about the EKAT development team and provide useful feedback under this section.

Announcements, Search, and First-Time User's Guide – The EKAT announcement section will highlight recent changes to the program that users will find helpful. The search function allows the user to perform a quick text search for relevant documents and topics in EKAT, or to perform an advanced search of on the World Wide Web. Program users can view the "First Time User's Guide" or view the automated demonstration, as seen in Figure 7, describing various functions within EKAT. The "First Time User's Guide" and demonstration give an overall introduction to EKAT and its capabilities.

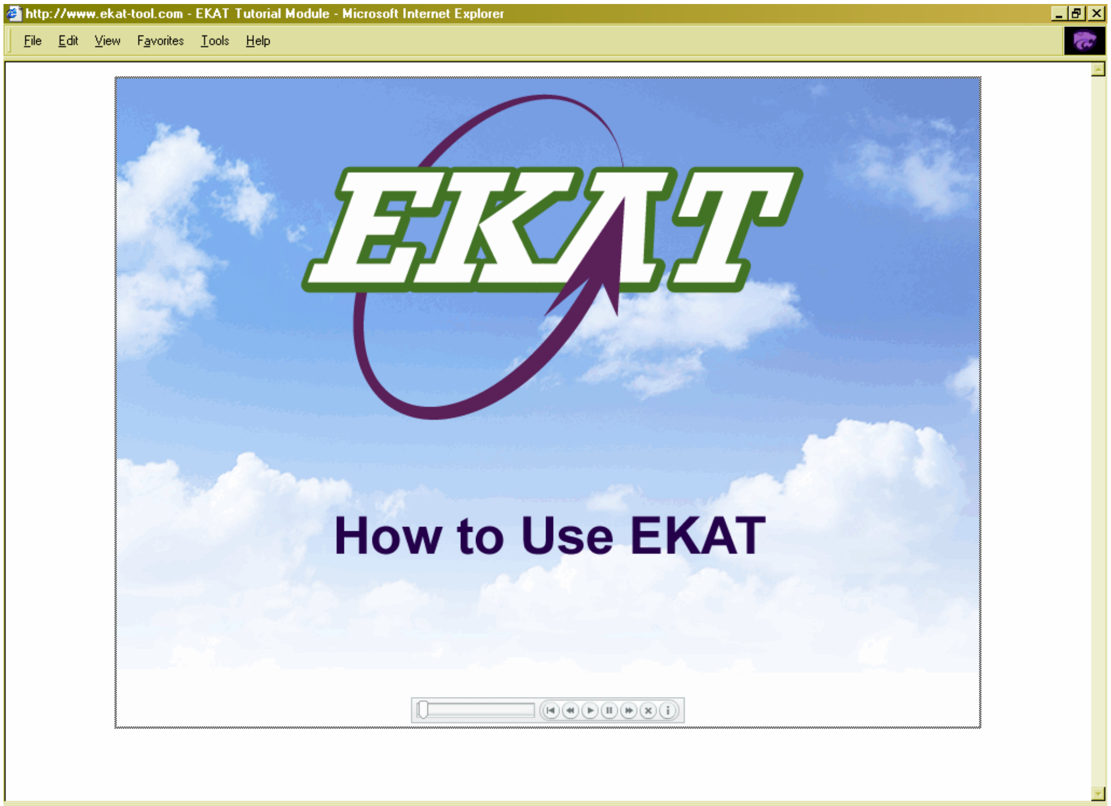

Figure 7. Title page of "How To Use EKAT" tutorial.
Video control buttons are available for mouse control on each page.

Wizard – If one is unsure which EKAT tool to use or where to look for information, he or she may use the EKAT Wizard for guidance. The Wizard is set up in a question/answer format to guide users to the section of EKAT which may be of most use.

On the first page of the Wizard, the user is asked whether he or she is seeking information about specific reporting requirements, such as the Programmatic Environmental, Safety, and Occupational Health Evaluation (for the U.S. Marine Corps); looking for general regulatory requirements or how to estimate air emissions or properly handle waste; looking for general chemical information; or how to respond to a chemical spill, should one occur.

Based on the user's initial inquiry, EKAT will lead him or her through a decision-tree matrix until the desired information is obtained.

The Wizard's opening page is shown in Figure 8.

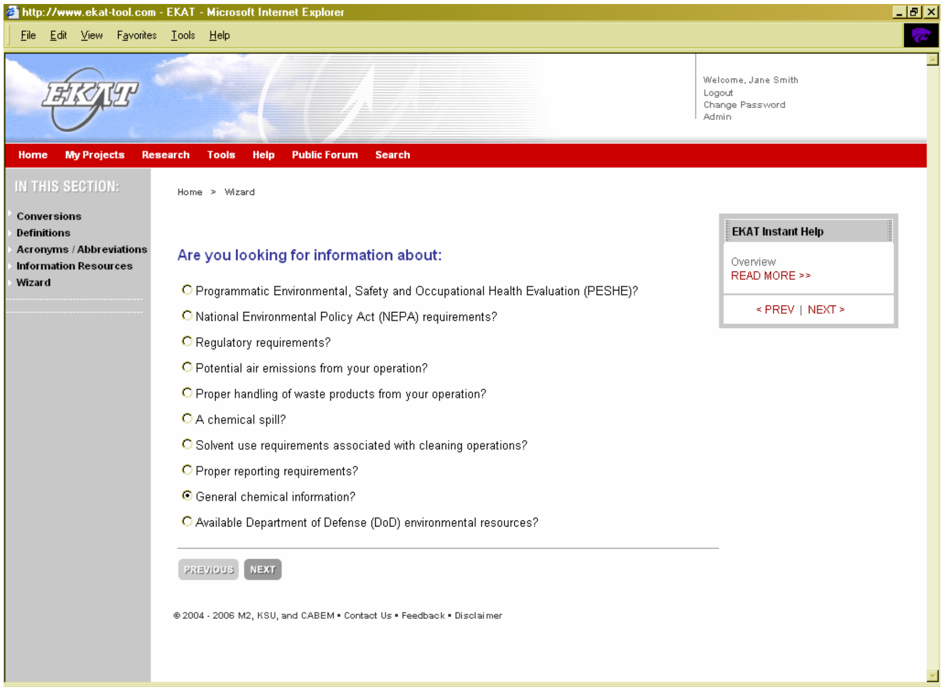

Figure 8. EKAT Wizard start page.

As an example, if the user were to inquire about the chemical and physical properties of a particular chemical, as in the case of DDT above, the Wizard suggests the following EKAT resources for information on these properties:

- View the Physical and Chemical Properties Guide for information on chemical characteristics.
- View the physical and chemical properties section of Web Research for additional resources.
- Within the National Library of Medicine's TOXNET databases, the Hazardous Substances Data Bank (HSDB) reports contain a chemical/physical properties section for each chemical.
- Access EPI Suite™ for physical/chemical property and environmental fate estimation models developed by the EPA's Office of Pollution Prevention Toxics and Syracuse Research Corporation (SRC).
- View the Periodic Table for specific information about individual elements.

In another example, a user might need information on the generation, transportation, disposal, or cleanup of hazardous waste. Results from the Wizard, suggest the following EKAT resources:

- View the Hazardous Waste Guide for information on federal and state requirements.
- View the Resource Conservation and Recovery Act (RCRA) IR for information on solid and hazardous waste management, the Remediation IR for information on treatment and cleanup of contaminated areas, and the Department of Transportation (DoT) Safety and Health IR for information on transport of hazardous materials.
- For chemical-specific regulatory information, go to My Projects to conduct an environmental screening, or screen an individual chemical using the quick environmental screening located under Tools to compare your chemical to RCRA hazardous wastes.
- Go to My Projects to conduct a Solvent Screening to evaluate solvents for hazardous waste compliance in the states of California, Georgia, Hawaii, Louisiana, North Carolina, South Carolina, and Virginia.
- View the "More Information" link on the Solvent Screening – Instructions Page for state-specific information on hazardous waste regulations in California, Georgia, Hawaii, Louisiana, North Carolina, South Carolina, and Virginia.
- For states other than California, Georgia, Hawaii, Louisiana, North Carolina, South Carolina, and Virginia, view the State Environmental Regulatory Agency list for contact information.

Tutorials – EKAT contains several tutorials to assist you with learning how to use EKAT most effectively. Topics include general information on how to use EKAT and the various sections of the program, estimating air emissions, and NEPA process training. The system has been set up so that most computers are able to automatically play the tutorial of choice by simply clicking on the appropriate link in EKAT.

My Projects – "My Projects" and the EKAT Project Manager allow multiple EKAT users to centrally organize and reliably document environmental solutions, while working collaboratively to generate reports and make decisions.

While much of what has been discussed earlier in this article involves EKAT directing the user to various pieces of information inside and outside of the program, much of the automated assistance EKAT can give in environmental evaluations, such as the environmental screening tool mentioned earlier (Figure 6), is found under "My Projects." Once in "My Projects," an EKAT user can choose to work on existing projects, either as the primary individual (the owner of the project) or as a participant on a project to which he or she has been invited to provide input. The user can also be asked to simply review existing project work (a project viewer), but not provide actual on-line changes.

Under "My Projects," one may opt to perform any of the following eight assessments: environmental screenings, solvent screenings, estimating the chemical concentrations in air (TECCA), estimating air emissions from a process (EmisCalc), estimate the environmental impact of a product over its life cycle (TRACI), examining NEPA or PESHE reporting requirements (which are specific to the U.S. Marine Corps), or examining a system assessment. These assessments are now discussed in greater detail.

- **Environmental Screening.** The environmental screening tool compares chemicals to federal regulatory compliance lists and highlights key health and safety concerns. An EKAT screen preview of environmental screening results currently common pesticide components is displayed in a summary table (Figure 9). The user can transfer the results to a more-detailed report, which can be saved to a Word or PDF document.

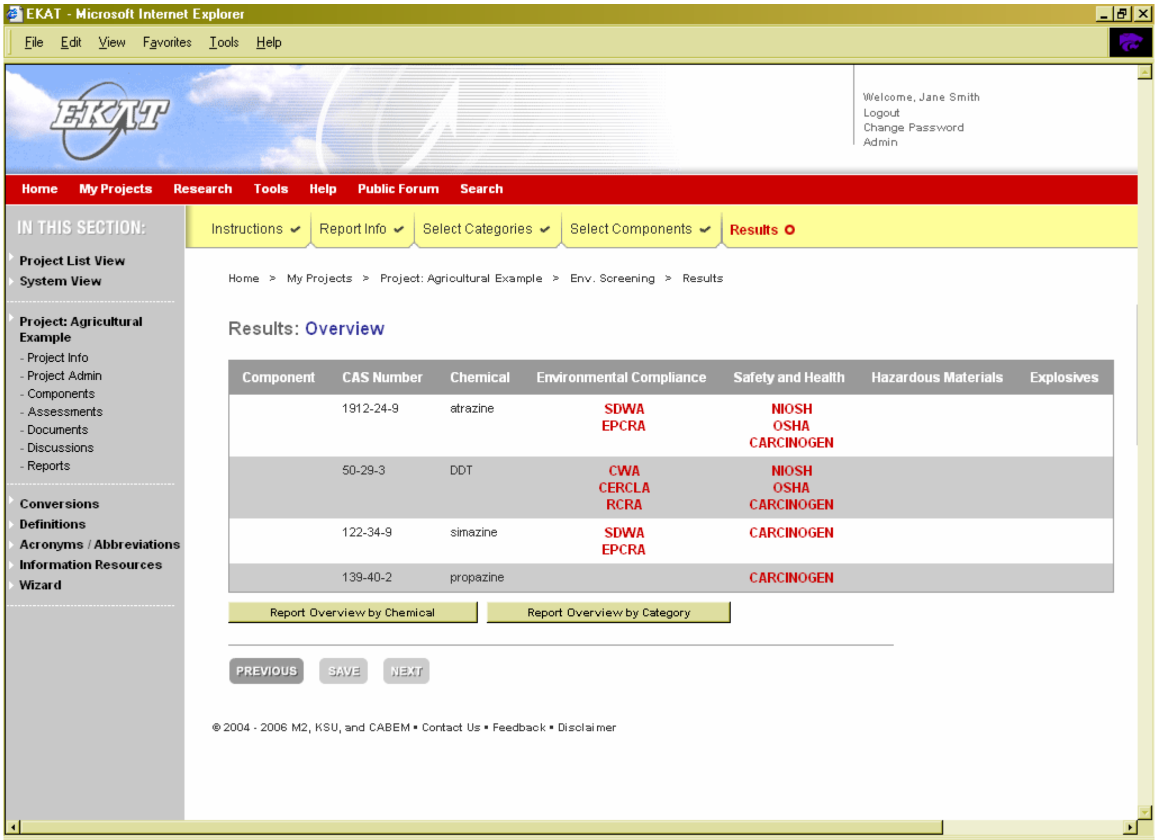

Figure 9. The Environmental Screening Results summary page.

- **Solvent Screening.** The solvent screening tool evaluates solvents for state air and hazardous waste compliance while highlighting specific Clean Air Act control technology requirements for solvent-cleaning operations. This tool is currently available for the states of California, Georgia, Hawaii, Louisiana, North Carolina, South Carolina, and Virginia.
- **TECCA.** This tool is used to estimate the average concentration of a chemical in the air of a room where a volatile liquid chemical release or spill has occurred.
- **EmisCalc.** EmisCalc estimates pollutant emissions associated with process activities, using EPA-approved air pollution factors. Results are useful for air-permitting requirements and can also be seamlessly integrated with the modified TRACI assessment for life-cycle evaluations. A screen image of the EmisCalc assessment process information choice is shown in Figure 10.

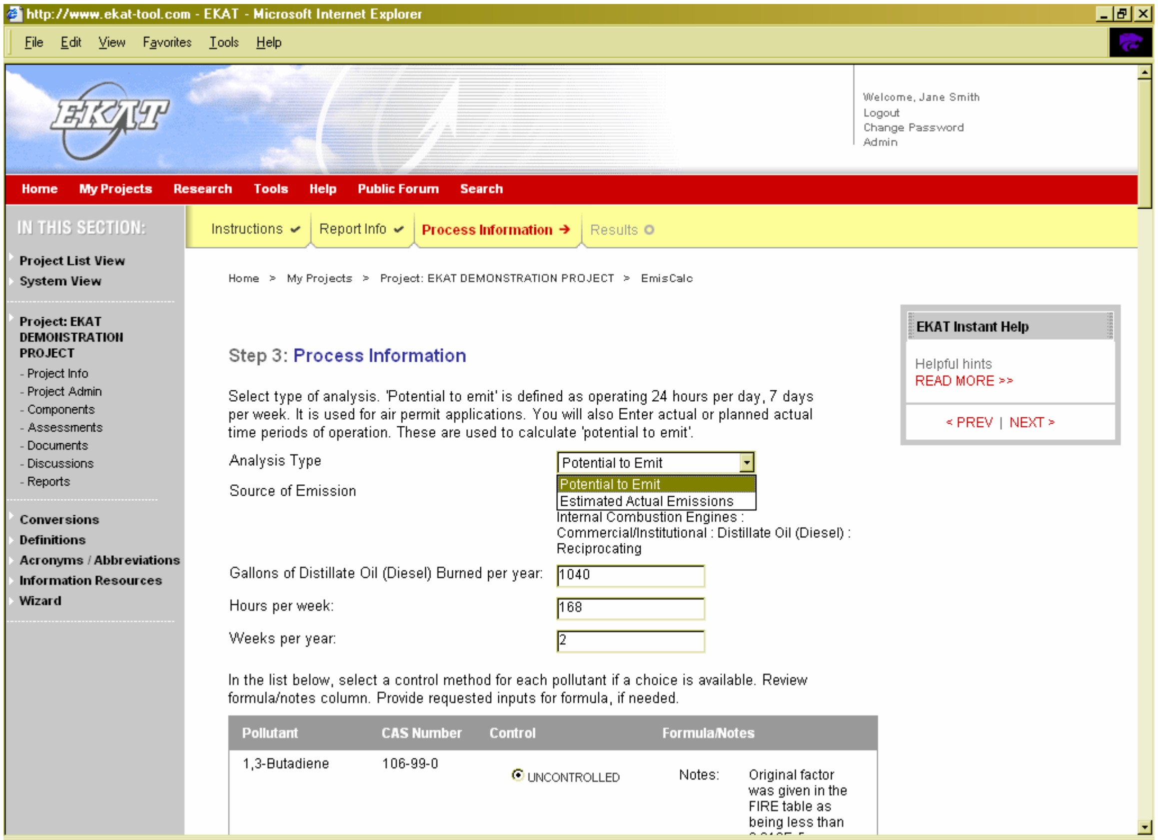

Figure 10. Process Information page for the EmisCalc Assessment.

- **TRACI for EKAT.** TRACI was developed by the EPA and adapted to EKAT. TRACI for EKAT allows the user to evaluate the environmental impact of chemical emissions to air or water over a product's life cycle and to make pollution prevention decisions based on this information.
- **NEPA Decision Tree.** The NEPA Decision Tree assists Marine Corps users in meeting federally mandated requirements under the National Environmental Policy Act (NEPA) to consider environmental and other related issues for proposed actions. While the majority of the components in this assessment decision tree are based on U.S. Marine Corps guidance (see Figure 11), there are aspects that the non-DOD user may find useful, specifically Step 1, determining whether a product or activity has a potential environmental impact. The user is advised to examine this tool and use as appropriate.

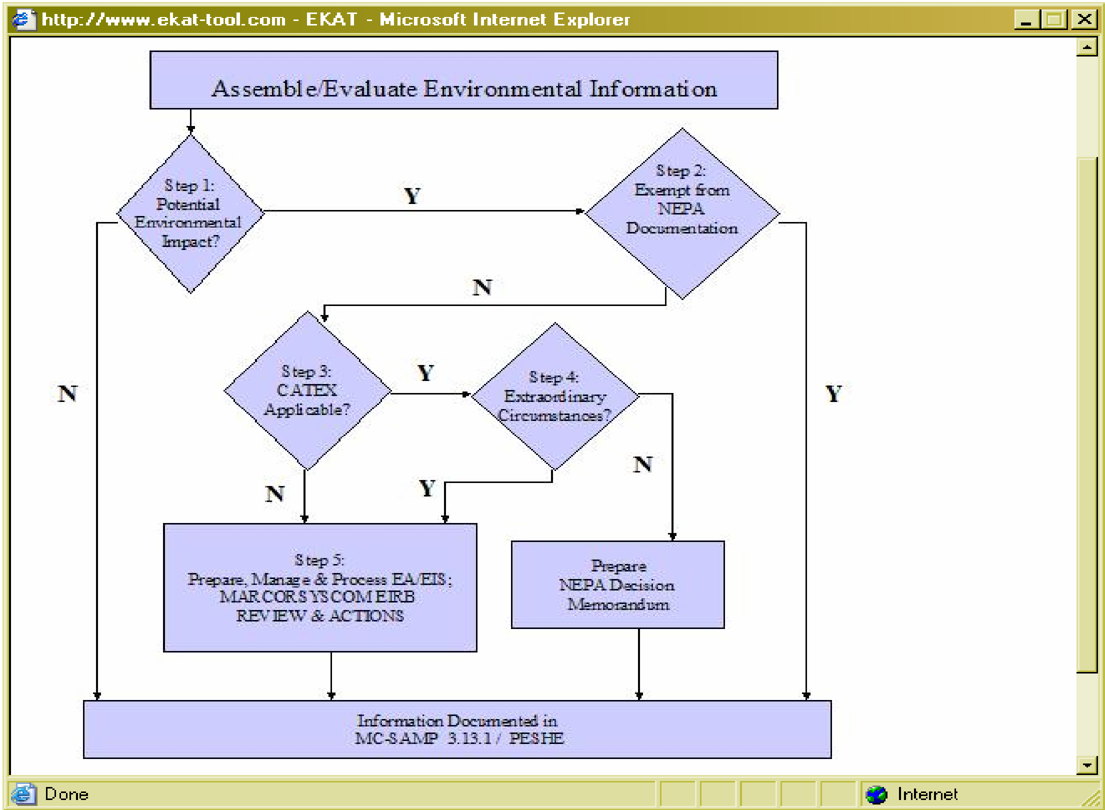

Figure 11. U.S. Marine Corps decision flowchart for National Environmental Policy Act (NEPA) evalutions.

- **PESHE Report Generator.** The PESHE Report Generator helps create a Programmatic Environmental Safety and Occupational Health Evaluation for the Marine Corps by using information inputted by the user and results of EKAT assessment reports for the project. This report can then be saved to a Word document for additional work.
- **Systems Assessment.** Development for this tool is underway. The systems assessment tool provides an overview of environmental risks and recommendations for mitigating these risks for product systems. Information is organized by major subsystem for each product system.

Operating Systems

EKAT is a Web-based solution that can either run on an intranet (no outside user access besides local personnel) or on the Internet, which would allow people with Internet access to access the system. EKAT provides for the needed authentication mechanisms to ensure a secure environment of the sensitive data gathered and provided by EKAT.

EKAT is based on Microsoft .net Framework Version 1.1. It is programmed using C#.net as the programming language. The database used is SQL Server 2000. The system is designed so it is capable to be hosted internally or by a hosting provider. Usage of the Microsoft .net Framework ensures a state-of-the-art platform for EKAT, and guarantees a flexible base to grow the system over time when new regulations and requirements require changes in the functionality and behavior of EKAT.

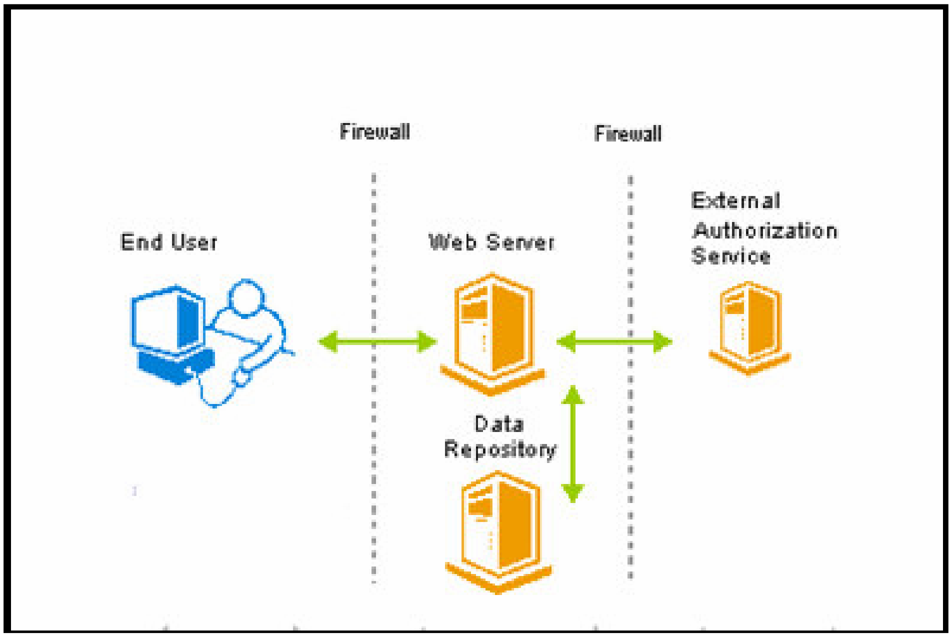

Figure 12. Basic representation of Internet deployment for EKAT.

For those who may have security concerns, the EKAT application can be hosted internally, as well as collocated or hosted externally. The application can be run on a single server with minimum requirements, or can be scaled for large traffic in which case the application and database can be maintained on separate mission-critical servers.

For the end user (the individual setting at the computer), EKAT is optimized to be used with MS Windows (98/NT4.0/2000/XP) with MS Word and other Office products, Adobe Acrobat, and a TCP/IP networking client running on the workstation. The client requires a browser and is optimized with the current version of MSIE (Microsoft Internet

Explorer) with JavaScript enabled. EKAT can be accessed with other compatible operating systems, productivity software, and browsers.

Conclusion

EKAT is a Web-based research, project management, decision-support tool to help identify and evaluate environmental and safety-related issues. The program contains basic information on technical and regulatory requirements and is a preliminary screening tool for potential issues of concern. EKAT also serves as a resource center, with links to other references, tools, and databases to assist users in their research efforts. The project management features of EKAT allow multiple users to work collaboratively on projects. This allows project team members to share information and documentation, as well as work collectively on different assessments or projects.

The tools and resources in EKAT are beneficial to both environmental professionals and those with no environmental background. While those who are familiar with EKAT or environmental regulations may be able to navigate quickly through the many resources the program has to offer, those who are less experienced may use the EKAT Wizard for guidance, view any of the automated tutorials, or use the First Time User's Guide and search features to find what they are looking for.

Resource features of EKAT provide a number of tools to assist in environmental evaluations, including information documents and guides, and links to environmental tools maintained by others outside of EKAT such as the EPA, the U.S. National Library of Medicine, the National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), the United States Fish and Wildlife Service, and many others.

In addition to being a resource center providing "one-stop shopping" for a variety of environmental topics, the projects component of EKAT provides automated assistance to users in their environmental evaluations, such as examining with the environmental screening tool environmental regulations that a material may be covered under, or estimating using the EmisCalc estimation tool based on EPA emission factors, the potential air emissions coming off a manufacturing process. The program also allows collaboration among EKAT peers by allowing various users to be project owners, participants, or viewers.

EKAT is available for review and use by individuals at www.ekat-tool.com. User feedback is welcome and desired for further program development. For specific questions about EKAT, or for an ID and password so that one may view the site, please contact the EKAT development team at ekat@ksu.edu.

Acknowledgments

Current EKAT development is funded by congressional appropriation and managed by MARCORSYSCOM. The primary focus of EKAT development is to assist MARCORSYSCOM in complying with environmental regulations and evaluating environmental issues associated with acquisition of weapons systems.

EKAT was designed and built by the team of M2 Technologies, Kansas State University, and CABEM Technologies as members of the NEER Consortium. M2 Technologies manages EKAT and provides application development and user support; Kansas State University provides subject matter expertise, application development, and content to the application; and CABEM Technologies provides software development and application development expertise to the team.

The NEER consortium addresses complex environmental issues affecting the health and safety of our air, water, and land. Its focus encompasses environmental problems across the spectrum of federal, state, and local responsibilities. NEER accomplishes its mission through scientific research, environmental training, independent assessment, technology transfer, and community services/assistance with a unique teaming approach of integrating scientific and operational problem solvers. For questions about EKAT, please visit www.ekat-tool.com or call NEER at 800-798-7796.

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RATIONAL METHODS FOR EVALUATING AND DESIGNING REMEDIATION PROGRAMS FOR AGRICULTURAL SOILS

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Abstract

Farming activities result in releases of hydrocarbon fuel. Applications to soil of excess salt-containing fertilizers have acceptable agronomic potential. These contaminates do not result in hazardous waste formation but reduce the productive capacity of the farmed area. This paper provides rational, low-cost methods for evaluating, remediating, and accessing clean closure of such non hazardous releases or purposeful applications. Many remedial programs mandated by government are over-designed, expensive, and have little or no clean-closure criteria based on agricultural needs. On the other hand, this paper relies on U. S Department of Agriculture published analytical methods and criteria, which have stood the test of time for more than 50 years. Also, the paper provides recommended clean-closure concentrations of total petroleum hydrocarbons, metals, and desirable chemical attributes for agricultural growth. Procedures include sampling contaminated and background soils, analyzing these soils, selecting appropriate soil amendments, calculating appropriate amounts of amendments, applying amendments, tiling the admixed soil, and verifying desired clean-closure concentrations results are attained. These procedures have been used at more than 1000 sites where hay, sugar cane, and rice are grown. Remediation of total petroleum hydrocarbon (TPH) to recommended concentrations in warm areas requires six months. Remediation of salt-impacted soil is slow, requiring as much as seven years, if the soil structure has been lost.

Key words: agricultural soil, hydrocarbon, salt, soil amendments, organic material, water

Introduction

Farming operations require use of gas and diesel-powered machines for tillage, planting application, harvesting, and transportation equipment. Also, if groundwater is pumped from under the farmland, liquid-fuel internal combustion engines are frequently used to power the pump. These engines are refueled in the field from portable or moveable supply tanks. Invariably, liquid-fueling operations result in releases of liquid hydrocarbons (measured as total petroleum hydrocarbon or TPH) to the farm soil. Diesel fuel, because of its short-chain hydrocarbons, acts as a herbicide, lowering the agronomic potential of the impacted area (Miller and Honarvar, 1975). Luckily, time, temperature, and naturally present biota will eliminate the problem eventually.

On the other hand, over-application of chemical fertilizers, the application of produced waters, e.g., water produced in conjunction with oil and/or gas production, or the application of other salt-containing waters increase the soil-saturated paste electrical conductivity (SPEC), sodium adsorption ratio (SAR), and sodium attached to the soil clay and measured as exchangeable sodium percentage (ESP), and reduce soil hydraulic conductivity. Alteration of these properties can reduce the agronomic potential of the affected area. Remediating salt-impacted soil is a highly technical and time-consuming effort, because of the soil structural changes caused by the presence of sodium. In most cases, remediation of salt-impacted soil requires five to seven years.

Remediation time can be shortened by applying proven agronomic analytical methods and avoiding a clean closure concentrations base on nonscientific criteria.

Land Treatment Overview

Land treatment can be divided into two categories: 1) total petroleum hydrocarbon impacted and 2) salt-impacted. In agricultural situations these conditions typically occur separately. However, it is possible for both conditions to occur at the same site, simultaneously. In either event, land treatment requires chemical and physical analysis of the soil and the unimpacted background soil, if background soil is used for dilution.

TPH-Impacted Soil

The intent of land treatment of TPH-impacted soil is to dissipate degradable petroleum hydrocarbon and condense more recalcitrant forms into humus using naturally occurring biota. Biota population growth is encouraged by providing nitrogen (N), potassium (K), and phosphorous (P) in specific concentrations commensurate with the hydrocarbon concentration. In addition to these amendments, the biota must be supplied with air and fresh water. All five of these amendments are desirable for successful remediation, but not always necessary. Some soils contain sufficient nitrogen, so the addition of water and air, and tillage, provides an opportunity for the biota to multiply and consume the hydrocarbon. However, tillage is necessary for the introduction of air into the near-surface soil.

Salt-Impacted Soil

Salt-impacted soil loses structure and forces cultivars to increase osmotic potential to obtain water from the soil. Reduced yield occurs from these conditions. Land treatment of salt-impacted soil requires chemical and physical analyses of the impacted soil and the unaffected background soil. Typically, these analyses include SPEC, SAR, ESP, CEC, and soil reaction (pH).

Salts inherent in seasoned spills are difficult and slow to treat. Salty (sodium-containing) soils are amended using calcium sulfate (gypsum) or similar calcium rich amendment and organic materials. The gypsum provides calcium to replace the sodium as it leaches from the clays into the vadose zone or drain field. Water is essential to leaching. During salt-impacted soil remediation, at least 1 inch of water per week is necessary. However, do not dike and flood the area, since the soil is deprived of air when flooded.

Typically, in agricultural operations, drain field are not needed, unless the impact is extreme (highly saline-sodic) or the field is underlain by impervious soil.

Organic materials increase soil CEC and moisture-holding capacity. The increased soil moisture reduces the salt concentration making for easier salt leaching. Also, tillage is required to provide mixing of the impacted soil with the underlying un-impacted soil and the organic and calcium amendments.

Impacted Soil Generation

Typically farming operators rely on gasoline and/or diesel-fueled engines to power trucks, tractors, harvesters, and other tillage, cultivating, harvesting, water-pumping, and transporting equipment. To avoid requiring these pieces of equipment to return to a central fueling location, temporary fuel storage is provided in the field close to the point of operation.

Spills from overflow accidents, hose ruptures, and careless operations result in fuel spills to the soil. The shorter the hydrocarbon molecule length, the more effective the fuel is as an herbicide. Thus gasoline and diesel have a severe impact on plant growth.

In clay-containing soils, the hydrocarbons attach tightly to clay particles. This bond is so tight; removing hydrocarbons mechanically or chemically from clay is not feasible. Accordingly, biological removal is the only economically viable method of reducing hydrocarbons.

Long-term application of fertilizers (chicken litter, potash fertilizer, ammonium sulfate); use of high-salt-containing irrigation waters; and salt-in-the-soil moisture raises the soil SPEC, SAR, and ESP. Increasing these values reduces the agronomic potential of the soil (Deuel and Holliday, 1997). Treatment to reduce these impact levels requires soil amendments, water, and time.

Soil Sampling

Land treatment of impacted soil requires knowledge of the chemical and physical composition of the impacted area and the background soil with which the impacted soil will be combined. Accordingly, the impacted soil and the background soils must be sampled, analyzed using accepted protocols, and the analytical results used in calculating appropriate soil amendments.

The impacted soil area should be delineated spatially and by depths of six inches or less can be remediated without excavation. Depending on the contamination concentrations below six inches in depth, the unimpacted soil (TPH $\leq$ 10,000 mg/Kg) may be left in place unremediated, since the TPH concentration is at or below the recommended limit.

Impacted Soil

The impacted area should be outlined by driving stakes along the outer boundary of the visibly impacted area. Generally, impact can be recognized by hydrocarbon staining or lack of vegetation.

A sample kit is generally available from the laboratory. It is prudent to have the laboratory include a Trip Blank to be analyzed to assure the sampler of no laboratory contamination of the sample bottles.

The delineated area should be made into a grid by driving stakes at 50-foot intervals in an orthogonal pattern. Each 2500-square-foot area should be sampled in an S-shaped pattern to a depth of 24 inches at 6-inch depth intervals. Typically, six to 10 sample holes per sample area provides representative information. Each sample depth in a single sample area must be combined separately and thoroughly mixed, and composite pint samples collected for each depth. This process is repeated for each depth interval. This forms a group of composite samples by depth. A single, quart-composite sample is formed for each depth interval by combining and mixing the totality of composite samples from each depth interval. Alternately, each sample can be identified as to location and depth, and all samples can be sent to the laboratory for compositing at the laboratory. Compositing is desirable to reduce analytical costs.

The samples of impacted soil are submitted to the laboratory for analyses. The samples must be accompanied by a Chain of Custody form, which is signed by each person relinquishing and accepting the samples. Samples should be iced and delivered to the laboratory within 24 hours of collection. Transport the sample in a closed, sealed ice chest containing enough ice so the ice remains until the samples are delivered to the laboratory. Samples containing hydrocarbons must be held at 4°C and analyzed at the laboratory within 28 days.

Delivery, typically, is arranged with FedEx, who will accept the shipment and sign the Chain of Custody form when the shipment is given to the transporter and when the samples are delivered to the laboratory.

Background Samples

Typically, impacted soil is mixed with background soils to provide dilution and supply hydrocarbon-consuming natural biota. Thus, several unimpacted background samples need to be collected. As a rule, two to three samples taken to 6-in depth are sufficient. The background soil samples should be shipped to and analyzed by the laboratory.

Soil Analyses

Care must be exercised in selecting the analytical laboratory procedures. Water analysis protocols are not satisfactory for soil analyses. In our opinion, the most satisfactory analytical procedures for soil are those included in the Louisiana Statewide Rule 29-B, Table 2. For best results in determining TPH concentrations, we recommend using gas chromatography with a flame ion detector (GC-FID), because as TPH remediates, it converts to humus, which is excluded from the analyses by molecular weight constraints and provides an indication of TPH removal more quickly and accurately. If infrared (IR) analysis is used, the humus fractions may be co-extracted and recognized by the method as TPH, and high TPH readings result. Although not encountered frequently in farm operations, barium is insoluble in water and mineral acids used in the EPA total metals digest protocol. We find the EPA protocol provides inaccurate and inconsistent barium analyses.

Waste Classification

In the U. S., waste is classified as hazardous if the characteristic and/or listed values are exceeded. Characteristic wastes are defined by EPA regulations as having the properties of ignitability, corrosivity, reactivity, or toxicity. It is possible for refined light hydrocarbons in soil to have a closed-cup flash point less than 140°F, making the soil a hazardous waste. However, this is seldom encountered in farm operations. Typically, weathering of the impacted soil causes the flash point to be above 140°F when sampled. Other hazardous properties are not encountered in agricultural wastes unless a very aggressive herbicide is used. If hazardous wastes are observed in farming operations, remediation as discussed in this paper is prohibited by EPA regulations.

Clean Closure Characteristics

Clean closure of an impacted soil must return the soil to its agronomic potential. Experience and laboratory analyses show clean closure is obtained when the soil properties are within the given range, depending on use, Table 1. The agronomic value of pH, etc. was developed by the U. S. Agriculture Department (1954). The metals concentrations come from the EPA sewage sludge rule (40 CFR §503.13) as modified downward based on our experience. The TPH recommended value was developed from the study by Miller and Honarvar (1975) at the University of Utah. These upper limit concentrations have been adopted by the state of Louisiana and many oil and gas operators. Also, the upper-limit concentrations have been used successfully more than 1,000 times for remediating soils growing corn, sugar cane, cotton, soybeans, wheat, and rice, among other crops.

Soil Amendments Calculations and Application

Two treatable impacting substances typically are encountered in agricultural operations, e.g. TPH and salts.

Total Petroleum Hydrocarbons

TPH is remediated by encouraging naturally occurring biota to convert the short-chain hydrocarbons into long-chain hydrocarbons resembling soil humus. The hydrocarbon concentration is known from the soil sample analysis. Avoid overloading the biota with too much hydrocarbon to consume. Accordingly, the initial loading rate is controlled in accordance with the soil temperature, e.g., the warmer the soil temperature, the higher the allowable TPH concentration, Table 3. Assuming the temperature is 80°F and the TPH analysis demonstrates five percent oil concentration in the soil, we can remediate the impacted soil without background soil dilution. The TPH calculations are based on the follows assumption and equations:

- soil temperature: >77°F, TPH; loading = 5%
- 1ac-6 inches deep = 2,000,000 lb based on 91.8 lb/cu.ft) (good approximation)
- ppm (parts per million by weight) [mg/Kg] x 2 = lb soil/ac - 6 inches deep
- typical oil contains 78% carbon (C) by weight
- % x 10,000 = mg/Kg
- C/N = 150/1 (based on experience)
- Assume the impacted site occupies 0.06 ac - 6 inches deep

1. carbon (C) content, in ppm (mg/Kg) of soil due to oil spill

   C% = TPH% x 0.78

   C% = 5.0% x 0.78

   C% = 3.9%

   C, mg/Kg = 3.9 x 10,000 (mg/Kg)/%

   = 39,000 mg/Kg

2. nitrogen (N) requirement

   C/N = 150/1

   (39,000 mg/Kg)/N = 150/1

   N = 260 mg/Kg

   N = (260 mg/Kg) x 2

   N = 520 lb/ac-6 inches

3. spill site occupies 0.06 ac - 6 inches deep

   N = 520 lb/ac-6 inches deep x 0.06 ac-6 in.

   N = 31 lb

4. N:P:K= 4:1:1

   P,K = N/4 = 31 lb/4

   P,K = 8 lb

Thus the impacted area can be remediated with 31 lb N, 8 lb P, and 8 lb.

If we use ammonium nitrate, which is 33% N, we require 142.5 lb ammonium nitrate. If we use superphosphate, which is 9.2% P, we require 87 lb superphosphate. If we use muriate of potash, which is 51% K, we require 16 lb muriate of potash.

Remediation Procedure

1. Remove all pooled oil.
2. Add **half of the ammonium nitrate** (NH_4NO_3), 47 1b (33%, N), 87 lb superphosphate (9.2%, P), and 16 lb muriate of potash (51%, K).
3. Disk and cross disk to 6 in to distribute fertilizer and aerate treatment zone.
4. After 6 to 8 weeks, **add half of the remaining ammonium nitrate** (NH_4NO_3), 23 lb; disk and cross-disk to distribute fertilizer and aerate treatment zone.
5 After 6 to 8 weeks, **add the remaining ammonium nitrate,** 23 lb; disk and cross-disk to distribute fertilizer and aerate treatment zone.
6. Irrigate as necessary to maintain treatment zone moisture between 50 and 80% of field capacity (1 inch of water per week).
7 After 6 to 8 weeks, sample the site to demonstrate cleanup level ≤1%, TPH. Re-treat as above, if necessary.

Applying the nitrogen in stages is necessary, since nitrogen sublimes and the full effectiveness is lost if all the nitrogen is applied at one time. Also, the addition of agricultural-grade hydrated lime speeds the TPH remediation (Deuel and Holliday, 2001), but be careful of raising the pH too high.

If the impact on the soil is surfacial e.g., < 6 inches deep, remediation may occur in situ by adding the amendments directly to the soil and disking the impacted soil and amendments into the unimpacted soil below the impacted soil. The analysis of the 0-6” composite sample must be at or below acceptable loading levels (Table 3). Then the impacted soil is mixed (tilled) with the amendments to 6”, using a 16 -20” disk pulled by a farm tractor. This procedure constitutes land treatment, since tillage provides air and distributes the amendments to the soil and biota.

If, on the other hand, contamination is deeper than 6 inches, the impacted soil must be excavated (and placed on the adjacent background soil in no more than 4 ft. lifts) or a crawler tractor must be used for pulling a large disk or ripper for deeper tilling.

Salt Amendments

The calculation of the salt amendments (gypsum) is beyond the scope of this paper. Typically, a conversion factor of 1 meq/100g CEC change = 1.7 tons gypsum/acre-ft is used. Those who are interested should refer to the book by Deuel and Holliday (1997) for details and calculation examples. Operators cannot apply too much gypsum or organic material, so amend the soil with gypsum and perform the calculations. Also, those operators experiencing salt contamination should immediately disk organic material into the impacted area e.g., hay, rice hulls, news print, horse stall straw, high-quality manure (avoid excessive chicken litter, because it can be very high in salts), etc. The sooner the application of calcium and organic material can be made, the less is the opportunity for structural damage to the soil, since time is required for the sodium to replace the calcium.

Organic material has a CEC value of about 300 meq/100g compared to 35-50 meq/100g for clay. Sequestering the salts in the organic material prevents the salts in high concentrations from entering the clays within the soil. Further, the organic material releases the sequestered salts slowly, reducing the impact of the salts on the groundwater.

Post-Treatment Analysis

An important consideration in soil remediation is demonstrating that remediation achieved the desired clean closure parameters, Table 1. This requires sampling the treated area after remediation is complete. For TPH, we recommend sampling and laboratory analysis of the samples after 24 - 32 weeks of treatment. Typically in the warmer portions of the U. S., 24 weeks is ample time for complete remediation. If the Table 1 criteria are not attained, repeat the remediation procedure using the TPH concentrations obtained from the post-treatment analysis.

Treatment for salt-impacted soil requires considerable time, e.g., five to seven years. We recommend sampling the treatment area at the end of each year of treatment. This procedure allows the operator to observe the remediation process progress and provide support for the assertion of clean closure. Again, if the long-term remediation concentrations (Table 1) have not been attained, remediation should be repeated based on post-treatment analyses.

Discussion

Remediating soil or waste to agricultural acceptable concentrations provides an economical and effective method for returning soil/waste to useful purposes. Too often, regulators establish clean closure concentrations on the ability to analysis to low concentrations. These arbitrary concentrations are unnecessary and uneconomical. The goal of remediation is to return the soil to useable condition. Most often, the impacted soil was or will be used for growing cultivars. There is no reason to remove long-chain hydrocarbons (humus) from the soil, even though we have developed analytical protocols which allow analysis to extremely low concentrations.

The TPH clean closure concentration of 1 percent (10,000 mg/kg), at most, will reduce the first-year crop yield after remediation by about 15 percent. The second-year crop yield will return to normal. The higher the soil temperature, the more quickly TPH will be removed by the biota.

In the case of salt-contamination remediation, the clean closure concentrations are in the range of normal agricultural soils used for crop growth. Thus, no decrease in yield is expected after remediation is complete. Temperature in temperate climates does not appear to reduce remediation time. However, remediation in hot, rainy climates (Brazil) show complete remediation to Table 1 concentrations is possible in about two years.

Conclusions

Bioremediation of hydrocarbon-impacted soil is easily, quickly, and economically accomplished in situ using naturally occurring biota. Bioremediation typically returns soil to reasonable agronomic potential in 24 weeks. Remediation of salt-impacted soil requires five to seven years of treatment. Immediate application and tillage of organic matter and/or gypsum reduces lose of soil structure, which causes protracted remediation time.

Nomenclature

CEC = cation exchange capacity, meq/100g

ESP = exchangeable sodium percentage, %

K = potassium, mg/kg

Ca = calcium, mg/kg soil or meq/liter water

Mg = magnesium, mg/kg soil or meq/liter water

Na = sodium. mg/kg soil or meq/liter water

P = phosphorous, mg/Kg

pH = hydrogen ion concentration, s.u.

SAR = sodium adsorption ratio, unitless

SPEC = saturated paste electrical conductivity, mmhos/cm

TPH = total petroleum hydrocarbons, %

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Table 1. Acceptable Clean Closure Values

	UPLANDS	
VALUE	**FOREST/ RECREATION**	**FARMING/RESIDENTIAL**
pH	5–8.5	5–8.5
SPEC (mmhos/cm)	4-8	2-4
SAR	< 14	< 12
CEC (meq/100g)	> 15	> 15
ESP (%)	< 15	< 15
METALS	**(mg/Kg)**	
Arsenic	40	
Barium	40,000	
Cadmium	10	
Chromium	500	
Lead	500	
Mercury	10	
Selenium	10	
Silver	10	
Zinc	500	
Organics	**Percent**	
TPH	1	

Table 2. Analytical Methods

Component/Table	Method	Reference
Total Petroleum Hydrocarbon/ Tables 2, 10, 11&12	EPA 8015	Deuel & Holliday
Total Metals/ Table 6	EPA 3050B	SW-846
Physical & Chemical Analyses/Tables 2, 10, 11 & 12	29-B	Louisiana Statewide Rule 29-B

Table 3. Initial TPH Loading Rates for Oil Light Oil

Mean Annual Soil Temperature ─ °F	Loading Rate ─ Percent TPH
> 77	**5**
58 - 76.9	**4**
76.8 – 46.4	**3**
<46.4	**0**

TRANSFER OF CERCLA REMEDIATION TECHNOLOGY TO AGRICULTURAL PROBLEMS: REDUCTIVE DECHOLORINATION TO ADDRESS AGRICULTURAL CONTAMINATION

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Abstract
Enhanced reductive dechlorination (ERD) has rapidly become a remedy of choice for use on chlorinated solvent contamination when site conditions allow. With this approach, solutions of an organic substrate are injected into the affected aquifer to stimulate biological growth and the resultant production of reducing conditions in the target zone. Under the reducing conditions, hydrogen is produced and ultimately replaces chlorine atoms on the contaminant molecule causing sequential dechlorination. Under suitable conditions, the process continues until the parent hydrocarbon precursor is produced, such as complete dechlorination of trichloroethylene (TCE) to ethylene. The process is optimized by use of a substrate that maximizes hydrogen production per-unit cost. The in situ method both reduces cost and accelerates cleanup. Successful applications have been extended from the most common chlorinated compounds, perchloroethylene (PCE) and TCE and related products of degradation, to perchlorate and even explosives such as RDX and trinitrotoluene on which nitrates are attacked in lieu of chloride. In recent work, the process has been further improved through use of food industry wastewaters available at little or no cost. With material cost removed from the equation, applications can maximize substrate loading without significantly increasing cost. Extra substrate loading both accelerates reaction rates and extends the period of time over which reducing conditions are maintained. In ongoing work, the technology is being applied to carbon tetrachloride contamination from grain elevators. This application represents an interesting waste minimization/re-use since the food waste comes from agricultural production. Design and results to date will be presented, along with an evaluation of the approach for application to other agricultural issues such as nitrate residues from fertilization.

Key words: enhanced reductive dechlorination, organic substrate, nitrates, remediation

TECHNO-ECONOMIC ANALYSIS FOR INTEGRATED BIOMASS ENERGY SYSTEMS

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Abstract
Interest in the synergistic integration of biomass energy systems to improve overall energy efficiency and economical feasibility is growing due to price increases for natural gas and petroleum. Two operations that are found to benefit from such integration are ethanol plants and confined-animal feeding operations (CAFOs), and several facilities are currently being designed and built in the United States. The primary benefits being evaluated so far for this integration are (1) the ability to use animal manure to produce methane via anaerobic digestion and use the methane to provide energy for ethanol distillation; (2) the ability to use distillers' grains on-site, without shipping or extensive drying, as animal feed; and (3) the ability to use processed manure as fertilizer for nearby fields. We are currently performing techno-economic analyses to investigate the most relevant aspects of integrated biomass energy systems, including (1) improvement of energy efficiency through the use of high-performance anaerobic digesters and the optimization of energy and thermal systems; (2) management of water streams for the recovery of nutrients and potential for water reuse; (3) management of gaseous streams through recovery of carbon dioxide; (4) production of solid by-products through the collection of Class A biosolids from a digester; and (5) precipitation of other compounds, such as struvite, to be used as fertilizers. The proposed techno-economic analyses will provide necessary information for evaluating energy and environmental benefits, and the feasibility of constructing integrated biorefineries. This information will help CAFO owners make decisions on the best alternatives for their site-specific options and needs.

Keywords: ethanol, anaerobic digestion, methane, manure

Introduction

As a result of industrialization, confined-animal feeding operations (CAFOs) have increased in number and size, along with higher animal densities on relatively small land areas. Based on the 1997 census of agriculture, the USDA reported more than 25,000 CAFOs (beef, cattle, swine, and poultry farms), equivalent to more than 2,300,000 confined-animal units[1] in the state of Kansas (Kellogg et al., 2000). These facilities require the removal of more than 23 million tons of manure per year. Currently, the most common practice to treat animal waste is through lagoons, which require relatively low capital investment, but generally do not provide the potential for harnessing energy and present a number of environmental risks, including release of excess nutrients, odors, and emissions of greenhouse gases (GHG).

Advanced technologies for animal waste treatment include high-performance anaerobic digestion (HPAD) and gasification (Overcash et al., 1983). These alternatives exhibit two major advantages over conventional systems: first, the recovery of energy through the of effluent gases, i.e., methane-rich biogas and hydrogen-rich syngas; and second, reduction in emissions of GHG. Biogas recovery through anaerobic digestion is most effective when the solids content of the waste from the CAFO is not higher than 10% (e.g., swine waste flushed from the barn). On the contrary, syngas production through gasification requires solids with low moisture content (e.g., cattle waste collected from open lots). Thus, the selection of one over the other will depend on the type of animal and the site-specific waste management practices in each CAFO.

A favorable alternative is to utilize the generated heat to supply the energy requirements of a nearby ethanol plant. Success of such an approach would depend on a proper design that takes into consideration site-specific factors, including the following:

A. Location, including accessibility to raw material supplies, climatologic factors (e.g., rainfall and evaporation rates, wind velocity, etc.), land availability for excess nutrient disposal, soil characteristics, and surface and underground water resources.
B. Proximity to populated areas, industrial complexes (e.g., ethanol plants, oil and/or gas extraction facilities), and agricultural complexes (e.g., other CAFOs, crop production, etc.).
C. Operation of CAFOs, describing the number of animals, type of animal, and stage of growth (i.e., production phase); housing system; manure collection and disposal methods; manure applied acreage; frequency of manure application; and energy usage in the forms of heat and electricity.

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(1) An animal unit represents 1,000 pounds of live animal weight.

D. Potential environmental problems and ways to minimize negative impacts.

Evaluation of these factors through feasibility studies and technoeconomic analyses is necessary to estimate the success potential of integrated biomass energy systems (i.e., biorefineries).

Design of an Integrated Biomass-Energy System

A hypothetical case was created as an exercise for a group of undergraduate students in the Chemical Engineering Design course. The case consisted of a confined-animal feeding operation with 150,000 hogs housed in 150 barns; the barns would house 1,000 hogs each and would be located in clusters of 10; hence, the operation would have a total of 15 clusters, which would be distanced 50 yards from each other. The hogs would be fed with a sorghum-rich diet, to which wet distiller's grains were used as supplement to reduce the hog feed costs as shown in Table 1. Average feed composition and amount for each barn.

Table 1. Average feed composition and amount for each barn

Feed	Average (%)	Amount (kg / day barn)
WDG [(1)]	11.1	558
Sorghum	40.0	1,818
Wheat	31.6	1,436
Soybean	15.7	661
Calcium Carbonate	1.5	68
Lysine	0.10	5
[(1)] WDG: Wet distillers grains; average moisture from 65 to 70 %		

The wet distillers grains would be obtained from a nearby ethanol plant and would be fed to the hogs as a slurry, minimizing costs of processing (current approach is to dry and pelletize the WDG). To assure safety and livestock health, the WDGs would be cooked for a short period.

Manure characteristics, as shown in Table 2, were obtained from reported literature averages (Overcash et al., 1983).

Table 2. Manure characteristics.

Stage	% Animals	Size (kg/head)	Manure (kg)	Moisture (%)
Nursery	25	15.9	1.0	90.0
Growing	25	29.5	1.9	94.0
Finishing	38	68.1	4.4	88.0
Gestation sow	8	125	3.8	90.5
Sow and liter	2	170	14	91.0
Boar	2	159	5	91.0
Average	100		4.5	89.7

A mass balance around the CAFO was determined, as shown in Table 3.

Table 3. Mass balance around the hog feeding operation.

In		Out	
Component	Flow (kg/day)	Component	Flow (kg/day)
Hog feed	681,818	Total Manure	1,065,341
WDG	83,628	TS	68,182
Sorghum	272,727	VS	54,031
Wheat	215,455	BOD	21,900
Soybean	99,099	COD	55,853
Ca. Carb.	10,227	TKN	3,613
Lysine	682	P_2O_5	3,750
Water	383,523	NH_4-N	1,233
Total	1,065,341	Total Manure	1,065,341

The manure waste from the hog farm would be utilized to produce biogas through anaerobic digestion; biogas would then be used to generate energy through a boiler. Three anaerobic digesters of equal volume (5805 m^3) were designed to handle the waste. Reasons for a design that includes three digesters included (1) reduction in total volume to be handled by a single digester; (2) contingency when 1 digester is not in operation, e.g., during the periodic drainage of solids; and (3) provision of a stable and continuous supply of biogas to boiler. The digesters were designed to operate at thermophilic conditions (55°C) so that Class A biosolids could be generated. The optimized hydraulic residence time (HRT) was 15 days, with the manure diluted to 6.4% solids for optimal performance. A settling tank around each digester was included to facilitate the settling and recycle of biosolids. Figure 1 shows a schematic of the digester.

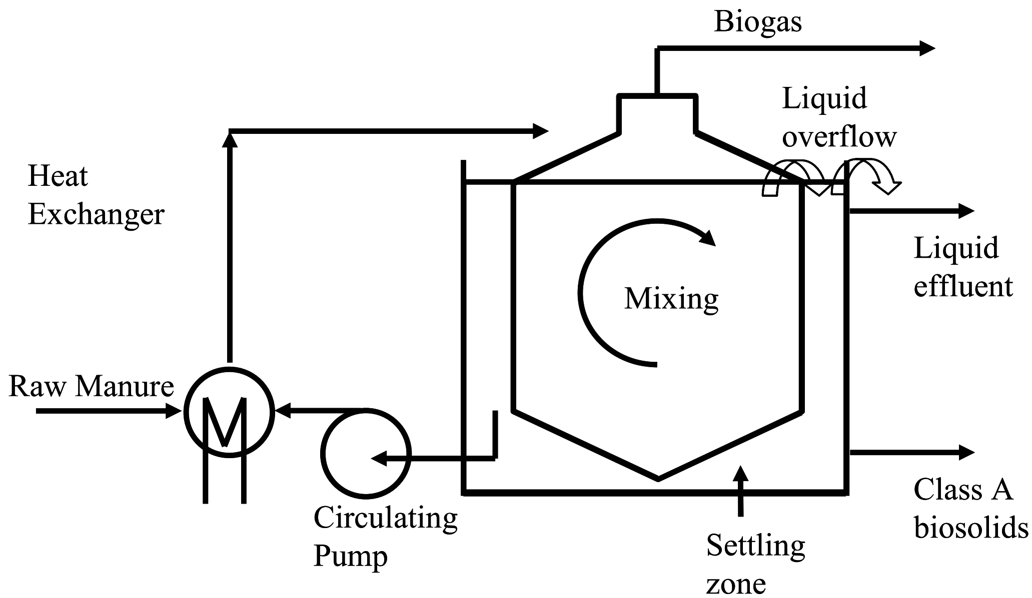

Figure 1. Schematic of the anaerobic digesters.

The mass balance around the digesters and settling tanks is shown in Table 4. It was estimated that each digester would generate about 27,000 m^3/day of biogas containing 61% methane, with a balance of carbon dioxide and trace amounts of ammonia and sulfur dioxide.

Table 4. Mass balance around digesters and settling tanks.

Parameter (kg/day)	Digester		Settling tank	
	In	Out	Liquid out	Solids out
TS	68,182	35,590	12,460	23,130
VS	54,031	23,260	7,687	15,580
COD	55,853	33,770	11,260	22,510
NH_4-N	1,233	2,208	1,287	922
TKN	3,613	4,052	2,216	1,837
Biogas (L/day)	-	38,420,000	-	-
CH4 (L/day)	-	23,410,000	-	-

The biogas produced by all three digesters would generate methane with combustion energy of about 1,000,000,000 kJ/day; this would be enough to supply the energetic requirements of an ethanol plant that would produce about 115,000 liters of ethanol/day and 84,000 kg of WDG/day. The digesters also would produce 970,000 liters/day of liquid fertilizer and 100,000 liters/day of class-A biosolids. Analysis of the ethanol plant included the cooker, fermenter, and distillation column; it was estimated that to achieve the production of ethanol, approximately 11,000 bushels of corn/day would be needed (McAloon et al., 2000). The ethanol plant was designed with a feed ratio of 10:1 liters of feed to liters of ethanol and would be in operation 330 days/year. An overall mass balance for the ethanol plant is shown in Table 5.

Table 5. Overall mass balance around ethanol plant.

Item	Cooker		Fermenter		Distillation column		
	In	Out	In	Out	In	Distillate	Bottoms
Corn (kg/day)	274,892	-	-	-	-	-	-
Water (L/day)	990,560	-	-	1,086,720	1,086,720	4,760	1,081,960
Nutrients (kg/day)	165	-	-	-	-	-	-
WDG kg/day	-	83,628	-	-	-	-	-
Ethanol L/day	-	-	-	120,747	120,747	115,148	6,037

Energy requirements for the integrated system were estimated from energy balances, which included operation of the three digesters and the ethanol plant. Results are summarized in Table 6.

Table 6. Energy requirements for integrated system.

Process	Energy (kJ/day)	Energy (kJ/L)(*)
Ethanol plant	793,520,000	6,892
Cooker	126,575,000	1,099
Distillation reboiler	579,000,000	5,030
Other	93,212,000	764
Digesters	184,740,000	1,604
Total energy needed	978,260,000	8,496

(*) Units in kJ per liter of ethanol produced

Thus, the energy generated by the three anaerobic digesters would provide enough energy to operate the integrated system with a small surplus of about 21,101,000 kJ/day.

An economic analysis was also performed, following the procedures dictated by Peters et al. (2003). It was assumed that the hogs for the feeding operation would be purchased weighing approximately 22.7 kg for a cost of $183 per 100 kg and sold at a weight of 127 kg at a price of $145 per 100 kg (Barchart, 2006). Rate of weight gain of a hog is approximately 0.91 kg/day; therefore, the hogs would be sold and purchased again every 115 days, which would correspond to 2.86 cycles per year (1 year = 330 days). To obtain profit on the process, five products would be sold. These are ethanol, hogs, biogas, class A biosolids, and liquid fertilizer. It was taken into account that the biogas produced from anaerobic digestion is used to provide energy for the process. The results are summarized in Tables 7 and 8.

Table 7. Results from economic analysis of the integrated system.

Item	Cost ($)
Ethanol plant	
Direct costs	33,703,200
Indirect costs	14,061,600
Hog farm	
Direct costs	44,880,000
Digester	
Direct costs	4,899,511
Indirect costs	1,858,334
Fixed capital investment	99,402,645
Working capital (15%)	14,910,397
Total capital investment	114,313,042

Table 8. Profitability of the integrated system.

Material	Price ($)	Units	Quantity	Units	$/year
Hogs	184.8	$/hog	150,000	Hogs/cycle	79,544,348
Ethanol	0.716	$/L	37,854,120	L/yr	27,100,000
Biosolids	0.060	$/kg	23,130	kg/day	457,974
Liquid fertilizer	0.022	$/kg	23,130	kg/day	253,447
					Total = $ 107,355,800
Gross annual earnings			$ 37,990,000		
Net present worth (*)			$ 45,375,000		
Payback period			$ 3.5 years		
(*) Minimum acceptable rate of return used was 15% (nominal of 13.98%).					

With these results, construction of this design is advised because of the high net present worth and the low payback period. Most of the profit would come from the selling of hogs. The difficulty to construct a system like this would be the large capital investment and the size of the operation.

Conclusion

Interest in the synergistic integration of biomass energy systems to improve overall energy efficiency and economical feasibility is growing due to the price increases for natural gas and petroleum. Two operations that are found to benefit from such integration are ethanol plants and confined animal feeding operations (CAFOs), and several of these facilities are currently being designed and built in the United States. The primary benefits being evaluated so far for this integration are (1) the ability to use animal manure to produce methane via anaerobic digestion and use the methane to provide energy for ethanol distillation; (2) the ability to use distiller's grains on-site, without shipping or extensive drying, as animal feed; and (3) the ability to use processed manure as fertilizer for nearby fields.

Overcash et al. (1983) estimate the net available energy from fresh manure to vary between 11,600 and 14,780 kJ/day/animal unit, depending on the type of animal. With more than 2,300,000 confined animal units in the state of Kansas, there are at least 9.5 trillion kJ/year that are currently underutilized. The Energy Information Administration reported 288.9 trillion kJ from natural gas consumed in Kansas in 2001. Biorefineries could provide at least 3% of this natural gas demand from biogas. Technoeconomic analyses are necessary to provide the necessary information for evaluating energy and environmental benefits and the feasibility of constructing integrated biorefineries. This information will help CAFO owners make decisions on the best alternatives for their site-specific options and needs.

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NEW INTEGRATED WASTES TO BIODEGRADABLE CARBON CRUDE OIL (BCO) BIOREFINERY FOR REMEDIATION OF POULTRY LITTER, MORTALITIES, AND PROCESSING RESIDUE

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Abstract

Extrusion-feeder liquefaction (EFL) technology coverts many lignocelluloses-rich organic solid waste material into a dense, sulfur-negligible, and heavy metal (arsenic, mercury, lead)-free liquid intermediate biodegradable carbon crude oil (BCO). EFL enjoys the protection of three patents issued, 19 patents in pending status, and 20 additional utility patents in discovery in the United States and globally. The EFL/BCO technology has been the subject of ongoing scientific and engineering development since 1971. The waste-to-energy process is accomplished under heat and pressure in the absence of oxygen, at moderate temperatures of 620 to 700 degrees F. The term EFL is a refining term that describes a plasticating extrusion process that is uniquely modified to continuously feed concentrated slurries of low-moisture organic flour material into a pressured retort system. The process is completed without the employment of water or combustion of any fuel. EFL process is odor and smoke free. EFL conversion technology produces a 100% liquid product that includes 53% BCO, 23% gray but easily cleaned water, 23% high-pressure CO_2, and 1% methanol that is captured and converted to methane to produce the heat for the plastication transfer. The EFL process does not employ acids, enzymes, gasification, or fast-pyrolosis technologies. Each of these technologies employ specific feedstock, require substantial external energy, and produce volatile gases that require specific and expensive infrastructure to de-water, handle, store, pump, transport, and dispense. As the EFL process exclusively employs waste feedstocks, the technology does not rely on uncertain futures contract harvests that must compete with important land and often-scarce water resources for food, forage, and fiber production. Multiple organic wastes are a perpetual, dependable, green, and renewable feedstock for the alternative new energy resource. EFL technology is batch-proven as an exciting new bio-refinery process that has produced BCO with double the BTU value of the feedstock, consistent low-moisture, oxygen and nitrogen content, good viscosity, and combustion characteristics that produce 30% less NOx emission, negligible SOx, complete combustion with low VOC emission, and almost no residue. Test results produced in batch plants in Albany, Oregon, and Tucson, Arizona, have proven BCO waste-to-energy conversions from more than 60 organic and petroleum-based waste stream feedstocks. The BCO tests demonstrate successful, consistent waste-to-energy bio-polymers that chemically resemble Texas light-sweet petroleum crude. These tests include observations and processes with poultry litter, mortalities, and processing residue. EFL conversion of poultry wastes to BCO effectively destroys most pathogens and micro-organisms that may lead to spread of the H5N1 "Avian Flu" virus, and other avian toxics such as ecoli. BCO provides petroleum offsets for bio-plastics feedstock; sulfur-negligible, heavy metal-free, 100% soluble blend fuel in petroleum refining for gasoline oxygenation; diesel lubricity and asphalts as direct-fire green and renewable fuel; and for fossil offsets in co-fire with coal and gas.

Key words: extrusion-feeder liquefaction, feedstocks, bio-refinery, NOx emissions, waste to energy

SMUD'S LEFTOVERS TO LIGHTS PROGRAM

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Abstract

The Sacramento Municipal Utility District (SMUD) created the Leftovers to Lights Program to help the utility achieve its commitment to its renewable portfolio standard (RPS), which calls for 23% renewable energy by 2011. The Leftovers to Lights Program focuses on helping convert problem wastes, such as animal manure, food waste, municipal solid waste, and other organic wastes into renewable resources for electricity generation, while providing local environmental and economic benefits. Several projects are in the early stages of development. Among them are projects to help local dairies install manure anaerobic digesters (AD) which facilitate manure disposal practices, reduce methane and VOCs emissions, mitigate groundwater contamination, and reduce odor. Gas that is produced from decomposition of manure (biogas) is used in an engine-generator unit (genset) for electricity generation, providing a substantial added value to the farmer. The dairy can then produce its own electricity, and any excess electricity can be sold to SMUD. SMUD has offered a 13% incentive to cover costs of installing a dairy digester. Dairies can obtain 25% funding from USDA Rural Development or up to $200,000 from USDA Natural Resources Conservation Service (NRCS), known as EQIP funds. Other funding sources may be available to offset the capital cost of the digester. In addition, SMUD is conducting a study on the technical and economic viability of a community dairy manure digester in the county of Sacramento. A community digester would help an aggregate of small dairies find a viable solution for their manure disposal and generate their own electricity. A central, large, shared digester (and genset) would be cheaper to build and easier to permit than individual digesters. The manure can be pumped from adjacent dairies to the digester. Also, in order to mitigate genset air emissions, SMUD is evaluating the best available technologies and methods to reduce pollution and comply with local and state emissions-control regulations. Engines running on biogas from dairy digesters face significant challenges due to a number of issues, such as impurities in the gas (hydrogen sulfide). Many low-emission technologies have been demonstrated in the U.S. over the past several years, but component failures have been a constant issue. This study will also identify the most reliable technology at a cost that dairy farmers can afford.

Key words: bioenergy, leftovers, anaerobic digestion, dairy manure, renewable energy

Introduction

SMUD is the sixth largest public municipal electric utility in the U.S. in terms of customer base, serving primarily Sacramento, California. SMUD is customer owned and directed by an elected board of directors. SMUD has long been committed to environmental stewardship and has been a leader in renewable energy, distributed generation, and energy efficiency.

Currently about 25% of SMUD's renewable energy comes from biomass. Local biomass projects can reduce greenhouse gas emissions and other air pollutants and may reduce risk of groundwater contamination. Greenhouse gases impact SMUD's ability to produce hydropower, which corresponds to a third of its energy supply, by reducing the amount of snowmelt runoff to reservoirs and causing earlier melting.

Several biomass conversion technologies have reached technical and economical maturity, such as manure digesters, landfill gas capture and conversion, direct combustion, and mixed-waste anaerobic digesters. These technologies benefit from sustainable, low, or no-cost fuel supplies and can often resolve other waste disposal challenges.

The first activity in our biomass program was to take an inventory of local resources and evaluate their potential as renewable energy fuels. We determined that the major biomass resource in the county is municipal solid waste in its various forms: green waste, food waste, landfill gas, wastewater treatment gas, and the organic fraction of municipal solid wastes (OFMSW). Additionally, agricultural sources provide waste wood from orchards and vineyards, and dairy manure from 43 Sacramento County dairies.

SMUD is helping three local dairies install manure anaerobic digesters (AD) which facilitate manure disposal practices, reduce methane and VOCs emissions, mitigate groundwater contamination, and reduce odor. Gas produced from the decomposition of the manure (biogas) is used in an engine-generator unit (genset) for electricity generation, providing a substantial added value to the farmer. The dairy can then produce its own electricity, and any excess electricity can be sold to SMUD.

SMUD has offered a 13% incentive to cover costs of installing a dairy digester. The dairies can obtain 25% funding from USDA Rural Development or up to $200,000 from USDA Natural Resources Conservation Service (NRCS), known as EQIP funds.

These three digester projects will reduce 910 tons/year of methane emissions, equivalent to approximately 17,000 tons of CO_2. To support development of local biomass projects, several internal policies were developed. In 2005, SMUD established a Biomass Net

Metering Rate and Biomass Interconnection Policy for projects owned by customers to serve their own electricity needs.

Because many dairies are too small to justify having their own digester, SMUD is conducting a study on the technical and economic viability of community dairy manure digesters. Two concepts are being studied and compared:

1) A shared digester would aggregate the manure from several dairies. This might be less expensive to build and easier to permit than individual digesters. Manure can be pumped to the digester from the adjacent dairies using flush-manure management practices.
2) An alternative concept is to pump the biogas from individual digesters to a shared genset. This might help mitigate air emissions from the genset, because cleaner engine technology is more available in larger sizes.

SMUD is evaluating the best available technologies and methods to reduce pollution and comply with local and state emissions-control regulations. Engines running on biogas from dairy digesters face significant challenges due to a number of issues such as impurities in the gas (hydrogen sulfide). Many low-emissions technologies have been demonstrated in the U.S. over the past several years, but component failures have been a constant issue. SMUD is performing several research and development projects to resolve these technological barriers. A side-by-side test of a low NOx Deutz engine is planned in addition to a project to demonstrate emission controls on small dairy biogas systems. This study will identify the most reliable technology at a cost that dairy farmers can afford. The best technologies will be demonstrated, and emission testing will be performed to validate emission reduction.

Food waste can provide a high-value organic feedstock that can be co-digested in dairy digesters, resulting in significant increases in biogas production. Food waste co-digestion projects can help divert the waste from landfills reducing fugitive methane emissions and can reduce the risk of groundwater contamination. A SMUD study identified commercial and residential source-separated food waste collection programs in 25 other cities, mostly on the West Coast. SMUD is investigating whether food waste collection would be right for Sacramento and whether food waste is best processed in on-site digesters at food processors, in centralized plants, or at wastewater treatment plants.

SMUD has sponsored a project at the University of California, Davis (UC Davis), where Dr. Ruihong Zhang in the biological and agricultural engineering department, is investigating the option of co-digesting different organic food wastes with manure. A computer model is being developed to predict the biogas yield from various combinations of organic wastes. In this project, UC Davis surveyed 45 businesses generating food waste and identified 1,200 bone dry tons of waste with a potential to produce 4,700 kWe of electricity. One business produces sufficient waste to supply a possible on-site digester; however, it may be necessary to combine several waste streams at one centralized digester located at its facility.

Many projects encounter permitting issues, and environmental impacts and benefits need to be examined before consensus can be gained among stakeholders. To this end, SMUD launched the Leftovers to Lights Working Group to develop a collaborative between businesses, regulators, municipalities, researchers, and environmentalists. The goal of the Leftovers to Lights Working Group is to facilitate the implementation of projects in Sacramento that benefit the local economy and environment.

BIOENERGY PRODUCTION FROM CODIGESTION OF FOOD WASTE AND DAIRY MANURE

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Abstract

The performance of continuously mixed anaerobic digesters were experimentally evaluated for treating manure, food waste, and their mixtures at 37±2°C and a hydraulic retention time of 20 days. The first mixture was composed of 32% and 68%, and the second was composed of 48% and 52%, of food waste and dairy manure, respectively. The percentage was based on volatile solids (VS). Digesters treating manure and the two mixtures showed stable performance at an organic loading rate (OLR) of 4 gVS/L. However, the digester treating food waste was not stable even at an OLR of 2 gVS/L, as indicated by high volatile fatty acid concentrations and low pH. The pH adjustment by adding hydrate lime to the food waste increased biogas production rate and yield. The 16S rDNA analysis results showed that the food-waste-derived library contained statistically greater numbers of clones related to the phyla *Thermotogae* and *Actinobacteria*; and the manure-derived library contained greater amounts of clones related to the phyla *Firmicutes*, *Bacteriodetes,* and *Spirochetes*. The archaeal population structure differed little between digester feed types and was composed of hydrogenotrophic, acetotrophyic, and methylotrophic methanogens. Results of this study showed that adding food waste into a dairy digester could significantly increase the energy production potential and improve the economics of the digester system.

Key words: dairy manure, food waste, biogas, renewable energy, microbial analysis

Introduction

Animal manures and municipal organic wastes are two resources for bioenergy production using anaerobic digestion technologies. Besides energy production, anaerobic digestion reduces the negative environmental impact resulting from direct land application and/or landfilling of untreated waste streams. However, many large dairy manure digesters do not have attractive economics with respect to investment returns due to the low biodegradability of dairy manure. Co-digestion of dairy manure and food waste is considered to be one of the effective options to improve the economics of dairy digesters, because food waste is a highly biodegradable substrate as compared with manure (Zhang et al., 2006).

Co-digestion refers to the digestion of two or more substrates in the same digester. It can offer many positive economical and technological benefits (Mata-Alvarez et al., 2000;

Mshandete et al., 2004; Parawira et al., 2004). Angelidaki and Ellegaard (2003) mentioned that an easily biodegradable substrate, such as food waste, would increase the concentration of active biomass in the digester, which in turn might have a higher tolerance to inhibitory compounds. Moreover, the presence of some inorganic complex (e.g. clay and iron compounds) in some substrates may overcome the inhibitory effects of ammonia and sulfide. Co-digestion of animal manure with other wastes has been studied by other researchers. According to Angelidaki and Ellegaard (2003), animal manure is an excellent carrier substrate when it is co-digested with some concentrated industrial wastes. Some suggested reasons for the suitability of manure as a carrier feedstock are as follows:

1. Manure has a relatively high moisture content (95-88% w.b.) that can help in the pumping and mixing processes.
2. It has a high buffering capacity that helps keep pH in the desired range for methanogenic archaea.
3. It contains all nutrients required for bacterial growth, which is essential for the digestion of industrial waste that has limited nutrient contents.

El-Mashad and Zhang (2006a) studied mesophilic batch co-digestion of dairy manure and food waste and determined biogas yields from manure, food waste, and two mixtures. The first mixture was composed of 32% food waste and 68% dairy manure. The second mixture was composed of 48% food waste and 52% dairy manure. The percentage was based on volatile solids (VS). Biogas yields after 30 days of digestion were determined to be 366, 657, 455, and 505 L/kgVS for manure andfood waste, the first and second mixtures with average methane content of the biogas being 66%, 54%, 62%, and 59%, respectively. In another study, El-Mashad and Zhang (2006b) evaluated the performance of completely mixed digesters, treating the two mixtures at 37^{o}C. The digesters fed with the two mixtures were stable at organic loading rates (OLRs) of 2 and 4 gVS/L.day. In that study, microbial structural analyses were not performed, and the experimental biogas yields of the mixtures were compared with the calculated yield of the manure using the model developed by Chen and Hashimoto (1978). This study was a follow-up study with the following objectives: (1) to compare the performance of completely mixed digesters for treating dairy manure and food waste individually and for treating the two mixtures of both substrates, (2) to calculate the increase in electricity production potential from a dairy digester after adding food waste, and (3) to characterize the microbial population structure in the digesters that treat the different substrates.

Materials and Methods

In order to compare the performance of digesters that treat the manure or food waste individually or their mixtures, two mesophilic (37±2^{o}C) completely mixed digesters, operated at 20-day hydraulic retention time (HRT), were tested in this study on the digestion of dairy manure and food waste. Detailed descriptions of the experimental setup for the digesters can be found in the paper by El-Mashad and Zhang (2006b). One digester was fed with dairy manure and the other was fed with food waste, each at an organic loading rate (OLR) of 4 gVS/L.day. After 20 days of operation, the second digester showed reductions in both biogas production and pH of its effluent and consequently the OLR was decreased to 2 gVS/L.day. When these two digesters were started, they were seeded with the effluent of two lab-scale digesters treating dairy manure. The digester headspaces were flushed with helium gas for five minutes to create anaerobic conditions. The digesters were allowed to sit for two days before feeding began.

Test results from the two digesters treating dairy manure or food waste were compared with results of the digesters treating the mixtures of these two substrates (El-Mashad and Zhang, 2006b). The food waste and dairy manure were the same for both studies.

Substrates characteristics

Dairy manure and food wastes used in this study were collected and characterized as described previously (Zhang et al., 2006; El-Mashad and Zhang, 2006b). The total solids (TS) and volatile solids (VS) contents (g/kg) of raw feedstock are shown in Table 1. The daily feeding volume was determined by adding the required amount of VS to give the desired OLR.

Measurements and chemical analysis

Daily biogas production from each digester was measured using a wet-tip meter. After each digester reached steady state, a biogas sample and an effluent sample were taken from the digester on three consecutive days. The biogas samples were analyzed for CH_4 and

CO_2 contents using a gas chromatograph (HP 5890 A) equipped with a thermal conductivity detector as described by Zhang et al. (2006). The digester effluent samples were analyzed for TS, VS, and total dissolved solids (TDS) using standard methods (APHA, 1998). The TDS, soluble chemical oxygen demand (COD_S), and volatile fatty acids (VFA) measurements were determined using the methods described by El-Mashad and Zhang (2006b). The pH and electrical conductivity (EC) of the effluents were measured with an Accumet pH/EC meter.

Microbial population structure analysis

In order to determine the bacterial and archaeal population structure within the digesters, 16S rDNA libraries were constructed, sequenced, and BLAST analyzed as described previously (McGarvey et al., 2005). Briefly, once the digesters reached steady-state conditions, samples were taken on three different days and DNA was extracted from them. The 16S rDNA sequences contained within these extracts were amplified via the polymerase chain reaction (PCR) using the eubacterial-specific primers 27f (5' AGAGTTTGATCCTGGCTCAG 3') and 1392r (5' GACGGGCGGTGTGTAC 3') as described by Lane (1991), or the archaea specific-primers 25f (5'-CYGGTTGATCCTGCCRG-3') and 1492r (5'-GGTTACCTTGTTACGACTT-3') as described by Dojka et al. (1998 and 2000). The PCR products were purified by ethanol precipitation, cloned into plasmid vectors using the Qiagen PCR Cloning Kit (Qiagen, Valencia CA) as per the manufacturer's instructions, and transformed into *E. coli* TOP10F' cells (Invitrogen, Carlsbad, CA) by heat shock (42^{o}C for 30 sec). Clones were plated on LB agar plates containing kanamycin (Km) (50 □g ml^{-1}), isopropyl-□-D thiogalactopyranoside (IPTG) (20 mM), and 5-bromo-4-chloro-3-indolyl-□-D-galactopyranoside (X-gal) (80 □g ml^{-1}). White colonies were selected and grown in 96 well plates in LB Km broth. Plasmids containing the 16s rDNA sequences were amplified using the TempliPhi 100 Amplification Kit (Amersham Biosciences, Sunnyvale, CA) as per the manufacturer's instructions. Sequencing reactions were performed using the BigDye Terminator v3.1 Cycle Sequencing Kit (Applied Biosystems, Foster City, CA), using the primer 1392r for bacteria or 1942r for archaea. Sequencing reactions were purified using the DyeEx 96 Kit (Qiagen, Valencia, CA); electrophoresis and readout were performed using an AppliedBiosystems 3100 Genetic Analyzer (Applied Biosystems, Foster City, CA). DNA sequences were edited manually to correct falsely called bases and trimmed at both the 5' and 3' ends using Chromas software (Technelysium Pty. Ltd., Helensvale Australia). Only sequences with unambiguous reads longer than 500 bp were used, and each read averaged approximately 600 bp. The predicted 16S rDNA sequences from this study were compared to 16S rDNA sequences in a BLASTable database constructed previously (McGarvey et al., 2004). This database contains sequences downloaded from the Ribosomal Database Project II (http://rdp.cme.msu.edu/download/SSUrRNA/unaligned/); Release 8.1. Comparisons were made using the program BLASTALL (ftp://ftp.ncbi/nih.gov/toolbox/ncbi_tools/) and a FASTA-formatted file containing the predicted 16S rDNA sequences. Operational taxonomic units (OTUs) were defined as clones with > 97% sequence identity. Comparisons of the 16S rDNA libraries were analyzed using Library Compare software (available at http://rdp.cme.msu.edu/comparison/comp.jsp), which estimates the likelihood that the frequency of membership in a given taxon is the same for the two libraries using the equation:

$$p(y|x) = \left(\frac{N_2}{N_1}\right)^y \frac{(x+y)!}{x!\,y!\left(1+\frac{N_2}{N_1}\right)^{(x+y+1)}}$$

where N1 and N2 are the total number of sequences for library 1 and 2, respectively, and x and y are the number of sequences assigned to an OTU from library 1 and 2, respectively.

Results and Discussion

Performance of the digesters

Average daily biogas and methane production rates and yields of different digesters are shown in Table 2. A steady-state operation was assumed after 60 days (3 HRTs) for the digesters. As can be seen, biogas production rates were 1.26, 0.51, 1.91, and 2.02 L/L.day for the digesters treating manure, food waste, and the first and second mixtures, while the biogas yields were calculated to be 314, 256, 476, and 504 L/kgVS, respectively. Average methane content of the biogas produced was 58%, 45.7%, 58.5% and 63.3%, respectively.

The digesters treating the manure and the two mixtures were stable as determined by low VFA concentrations and relatively neutral pH values (Table 2). The total VFA concentration in the effluent of the manure digester was 678 mg [acetic acid]/L, which is comparable to the VFA concentrations observed in other dairy-waste digester effluents (Martin, 2003). Acetic acid represented approximately 46% of the total VFA content.

The digester treating food waste was unstable at an OLR of 4 g VS/L.day (data not shown), thus the OLR was reduced to 2 g VS/L. day. Although the OLR was reduced, the digester continued to suffer from high VFA concentrations (6778 mg [acetic acid]/L), which resulted in low pH values (5.86) after two months of operation. Acetic acid was the major constituent of the VFAs (about 45%). Compared to the other digesters, the food-waste digester had a higher concentration of COD_{dis}. The accumulation of these intermediates (i.e. VFA and other organic compounds) indicated that the hydrolytic and acidogenic bacteria had a higher tolerance to low pH values and high VFA concentrations than the methanogenic archaea did (Cho et al., 1995).

After characterizing the effluent from the food-waste digester, the pH was increased to about 7.1 by adding hydrated lime, $Ca\ (OH)_2$. This addition resulted in increased biogas production. After about one month, the average biogas production rate and yield were 1.29 L/L day and 643.2 L/kg VS. The average methane content of the biogas was measured to be 64%. Although adjusting the pH with hydrated lime was effective in maintaining the pH within the proper range for methanogenic archaea, the amount of the lime added should be controlled in order to prevent the inhibitory effects of high calcium concentrations to methanogenic archaea (McCarty, 1964).

The measured VS reductions in the digesters were calculated to be 36.1%, 57.%, 42.2%, and 57.1% for manure, food waste, and first and second mixtures, respectively. The VS reduction in the manure digester is typical for dairy digesters (Dugba and Zhang, 1999). The measured, total dissolved solids were 15.8, 5.27, 17.7, and 15.3 g/L and the EC values were 5.78, 5.05, 5.7 and 6.53 mS/cm for the effluent of the digesters, respectively. It should be mentioned, that although the TDS and EC are commonly used as parameters for determining the salt contents of water, they do not accurately measure the salt concentrations in digester effluents. This is because the TDS in the digester effluents contain organic as well as inorganic matter. A more detailed study is required to determine the relationships between the TDS and the salt concentrations in the digester effluents.

Microbial population structure analysis

Bacterial 16S rDNA libraries containing approximately 500 clones were constructed from total DNA isolated from the effluents of the anaerobic digesters treating food waste, manure, and the two mixtures. Analysis of these data revealed significant differences between the libraries derived from the digesters treating food waste and manure (Table 3). Specifically, it was observed that the food-waste-derived library contained statistically greater numbers of clones related to the phyla *Thermotogae* and *Actinobacteria,* and the manure-derived library contained more clones related to the phyla *Firmicutes*, *Bacteriodetes,* and *Spirochetes*.

Co-digestion of food waste and manure in the two mixtures resulted in few differences between the resultant libraries, except for the greater abundance of sequences related to the *Chloroflexi* in the second digester and the small but statistically significant greater abundance of the *Bacteriodetes* in the digester treating the first mixture. However, when compared to the libraries derived from the effluents of the food waste or manure-digester effluents, they resembled a conglomeration of the two, in that both mixed-digester-effluent-derived libraries contain sequences related to the phyla *Thermotogae* and *Firmicutes* at levels that are intermediate to the food waste and manure-digester-effluent-derived libraries. Interestingly, both mixed-food waste and manure-digester-effluent-derived libraries showed significantly greater levels of the phylum *Chloroflexi* than either manure or food-waste-effluent derived libraries. However, it is unclear what specific selection parameter influenced their increase.

Archaeal 16S rDNA libraries were also constructed for each digester type. Analysis of these libraries revealed much lower levels of diversity than that observed in the bacterial libraries, with only one phylum, the *Eurychaeota,* present in each library (Table 4). Comparison of the libraries derived from the food-waste-digester effluent and the manure-digester effluent revealed small but significant differences between the orders *Methanosarcinales and Methanomicrobiales*. However, when the mixtures were digested, no significant differences were observed between the two digester effluents at the order level. It should also be noted that in all of the libraries, the most numerous operation taxonomic units identified were related to the order *Methanosarcinales*, followed by the *Methanomicrobiales* and the *Methanobacteriales*. Thus, the archaeal population structure differed little between digester feed type and was composed of a mixture of hydrogenotrophic, acetotrophyic, and methylotrophic methanogens.

Energy potential and economic analysis

Energy production potential from a dairy digester treating manure from 1,800 cows with and without adding food waste is shown in Fig.1. Without adding food waste, a daily electricity production of 4,667 kWh is predicted, which is equivalent to about 2.6 kWh/cow. day. After the addition of 19.1 or 38.2 tons (wet basis) of food waste a day, the daily electricity production potential would increase to 10,767 or 16,465 kWh/day, respectively, which represents the increase in the electricity production potential by approximately 2.3 or 3.5-fold , compared to the electricity potential for digesting the manure alone. It should be mentioned that in the pervious study by El-Mashad and Zhang (2006b), the electricity production potential from the same amount of manure was calculated to be 5313 kWh/day, based on the methane yield calculated from the model of Chen and Hashimoto (1978), which is higher in the yield determined from this study.

A preliminary economic analysis showed that based the tipping fee of food waste ($25 per ton (wet)) and biogas production of food waste, the payback period of the dairy digesters could be reduced from nine years for digesting manure alone to four years for co-digesting food waste and manure. A more detailed design of the digester for co-digestion of food waste and manure and its economic analysis are under investigation.

Conclusions

Based on the results obtained in this study, the following conclusions can be drawn:

1. Anaerobic digesters treating mixtures of dairy manure and food waste were stable at organic loading rates of 4 g VS/L.day, while the digester treating food waste alone was not stable even at 2 gVS/L.day. High VFA concentrations and low pH were found in the food-waste digesters as a result of the high biodegradation rate of food waste.
2. The microbial population structure of food-waste-digester effluent contained statistically greater numbers of clones related to the phyla *Thermotogae* and *Actinobacteria,* and the manure-digester effluent contained greater amounts of clones

related to the phyla *Firmicutes*, *Bacteriodetes,* and *Spirochetes*. The archaeal population structure differed little between digester feed types and was composed of hydrogenotrophic, acetotrophyic, and methylotrophic methanogens.

3. Adding food waste into the dairy manure-digester would significantly increase energy production potential and improve the economics of the digester system.

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Table 1. The TS and VS of raw dairy manure and food waste (standard deviations are shown between brackets).

Component	Dairy manure	Food waste
TS, g/kg	138.8 (1.5)	263 (0.9)
VS, g/kg	117.8 (1.4)	226.1 (2.0)

Table 2. Measured parameters for the effluent and biogas of the digesters (standard deviations are shown between brackets).

Parameter	Feed for the digesters			
	Manure	Food waste *	First mixture	Second mixture
Biogas production rate (L/L.day)	1.26 (0.07)	0.51 (0.13)	1.91 (0.05)	2.02 (0.35)
Biogas yield (L/kgVS)	314 (17)	256 (67)	476 (13)	504 (89)
Methane content of biogas (%)	57.95 (1.17)	45.70 (3.86)	58.5 (0.4)	63.3 (0.7)
Methane production rate (L/L.day)	0.73 (0.04)	0.23 (0.06)	1.12 (0.03)	1.276 (0.2)
Methane yield (L/kgVS)	182 (10)	117 (31)	279 (74)	319 (56)
COD_s (g/L)	5.64 (0.20)	15.32 (0.08)	3.60 (0.31)	6.69 (0.71)
Total VFA (mg[acetic acid]/L)	678 (74)	6778 (2377)	914 (373)	1876 (279)
Acetic acid (mg/L)	312 (6)	3011 (1040)	462 (82)	1021 (193)
Propionic acid (mg [acetic]/L)	7 (5)	1007 (393)	74 (37)	249 (248)
Iso-butyric acid (mg [acetic]/L)	345 (63)	506 (131)	364 (268)	576 (325)
Butyric acid (mg [acetic]/L)	3 (4)	982 (341)	8 (6)	18 (6)
Iso-valeric acid (mg [acetic]/L)	4 (3)	447 (212)	2 (3)	6 (3)
Valeric acid (mg [acetic]/L)	7 (4)	825 (273)	4 (4)	7 (4)
pH	7.57 (0.07)	5.86 (0.04)	7.53 (0.03)	7.66 (0.04)
TS (g/L)	58.60 (1.13)	19.11 (1.34)	54.6 (0.5)	40.3 (4.8)
VS (g/L)	47.03 (1.38)	14.68 (1.16)	42.8 (0.5)	30.8 (4.4)
TS reduction (%)	36.14 (1.23)	57.92 (2.96)	42.2 (0.5)	57.1 (5.2)
VS reduction (%)	39.62 (1.78)	62.31 (2.98)	46.4 (0.6)	61.5 (5.5)
TDS (g/L)	15.80 (1.11)	5.27 (0.89)	17.7 (1.4)	15.3 (0.8)
EC (mS/cm)	5.78 (0.39)	5.05 (0.24)	5.7 (0.27)	6.53 (0.03)

* No hydrated lime was added

Table 3. Percentage of bacterial 16S rDNA clones assigned to phyla in different digesters.

Phylum assignment	**Feed for the digesters**			
	Food waste	**Manure**	**First mixture**	**Second mixture**
Actinobacteria	**4.9**	**1.2**	**0.7**	**0.2**
Bacteroidetes	**14.4**	**21.7**	**17.6**	**9.6**
Chloroflexi	**1.8**	**1.4**	**6.6**	**16.1**
Deferribacteres	**0.4**	**ND**	**ND**	**ND**
Firmicutes	**27.7**	**58.1**	**46.7**	**49.7**
Planctomycetes	**ND***	**0.2**	**0.1**	**ND**
Proteobacteria	**2.6**	**5.8**	**3.6**	**2.6**
Spirochetes	**ND**	**3.5**	**4.5**	**4.4**
Thermotogae	**43.8**	**ND**	**10.9**	**9.3**
TM7	**ND**	**ND**	**0.1**	**0.2**
Unknown	**4.4**	**8.1**	**9.2**	**7.8**

*** None detected**

Table 4. Percentage of archeal 16S rDNA clones in different digesters.

Phylum assignment	**Feed for the digesters**			
	Food waste	**Manure**	**First mixture**	**Second mixture**
Phylum ***Euryarchaeota***	**100**	**100**	**100**	**100**
Order ***Methanobacteriales***	**17.2**	**19.3**	**13.2**	**16.5**
Family ***Methanobacteriaceae***	**17.2**	**19.3**	**13.2**	**16.5**
Order ***Methanosarcinales***	**44.0**	**58.8**	**64.8**	**66.0**
Family				
Methanosarcinaceae	**22.0**	**45.1**	**49.0**	**63.6**
Methanosaetaceae	**22.0**	**13.7**	**15.8**	**2.4**
Order ***Methanomicrobiales***	**38.8**	**22.0**	**22.0**	**17.5**
Family				
Methanocorpusculaceae	**6.2**	**3.0**	**1.9**	**1.2**
Methanomicrobiaceae	**32.6**	**19.0**	**20.1**	**16.3**

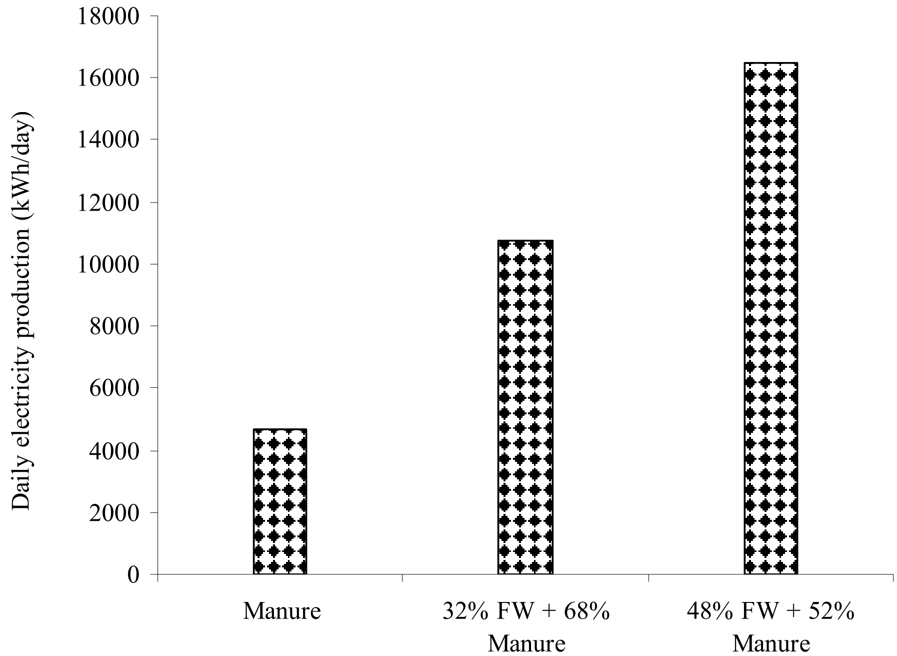

Figure 1. Electricity production potential from a digester treating manure alone or the two mixtures of manure and food waste.

Track 3
Resource Management

AVIAN REPRODUCTIVE SUCCESS UNDER DIFFERENT PESTICIDE-USE REGIMES ON AGRICULTURAL LEASE LANDS OF THE KLAMATH BASIN NATIONAL WILDLIFE REFUGES

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Abstract

Pesticide exposure and reproductive success were monitored in two avian species to evaluate the effects of pesticide use on wildlife at Klamath Basin National Wildlife Refuge Complex. Reproductive success of European starlings using artificial nesting structures was relatively high on both reference and pesticide-treated sites. Overall-mean clutch size and percent fledge in test plots were within the ranges of values reported for starlings. Percent hatch of starlings showed a positive correlation with crop type and a negative correlation with the number of fungicide applications. Other reproductive parameters evaluated were similar between pesticide-treated and reference areas. Significant brain cholinesterase reactivation indicated 14% (n=92) of nestlings found dead during the study were likely exposed to carbamate insecticides; whereas, cholinesterase reactivation analysis in apparently normal starlings suggested relatively low rates of exposure to both carbamate (<1%, n = 256) and organophosphate (3%, n = 256) insecticides. Chemical analysis of dietary items indicated nestling exposure to dicamba and 2,4-D herbicides, which are approved for refuge use. Analysis also indicated exposure to aldicarb, carbofuran, propazine, simazine, and dichlorprop, which are not approved for refuge use. However, all pesticides detected in the diet were below concentrations known to cause adverse effects in birds.

Key words: pesticides, birds, reproduction, kestrels, European starlings

Introduction

Tule Lake and Lower Klamath National Wildlife Refuges (NWRs) are located in northern California and southern Oregon, and serve as key spring/fall staging and over-wintering areas for migratory waterfowl. The refuges were established by Presidential executive order in 1908 (Lower Klamath) and 1928 (Tule Lake) on lands that had been previously developed for water delivery by the U.S. government and opened to homesteading, creating an inherent conflict between agriculture and wildlife interests. The conflict was stabilized by the Kuchel Act of 1964, which permanently placed refuge lands in governmental ownership, with the primary purpose of waterfowl management, but "…with full consideration to optimum agricultural use that is consistent therewith" (USFWS, 2005).

Accordingly, a total of 8900 ha of land at Tule Lake and Lower Klamath NWRs are leased to farmers under a program administered by the U.S. Bureau of Reclamation (USBR). Crops grown on refuge leases include small grains, alfalfa, potatoes, and onions. A consequence is that the federal lease lands at Klamath Basin Refuges receive several hundred pesticide applications/year.

Since 1964, the Klamath Basin NWRs have developed a suite of management tools to reduce the impacts of agricultural chemicals to wildlife, consistent with U.S. Department of the Interior (USDOI) and U.S. Fish and Wildlife Service (USFWS) policies (USDOI, 1981; USFWS, 1990). These include an established pesticide use approval process, integrated pest management, crop rotation, and a flood-fallow program. In spite of these programs, more than 50 pesticides are currently approved for use on the refuge lease lands (USFWS, 2002; USFWS, 2003). USFWS investigators have previously conducted field surveys to assess the occurrence of pesticide-related mortality incidents through carcass search efforts (Thomson et al., 1998; Snyder-Conn *il.*, 1999; Snyder-Conn and Hawkes, 2004). They recorded more than 100 fish and wildlife mortality incidents, but field and laboratory evidence implicating pesticides was generally lacking. However, carcass search efforts can underestimate pesticide-related wildlife mortalities, and carcasses are often not suitable for chemical analyses (Vyas, 1999).

We initiated the present study to evaluate the effectiveness of refuge management programs in reducing pesticide risks to wildlife by evaluating reproductive success in two non-target avian species (i.e., species subject to direct and dietary incidental pesticide exposure). We selected American kestrels (*Falco sparverius*) and European starlings (*Sturnus vugaris*) as the species of interest because they are both cavity-nesting species adaptable to nest boxes, occur on the Klamath Basin NWRs, and are also commonly used in toxicological studies (Lincer, 1975; Cabe, 1993; Trust et al., 1994; Smallwood and Bird, 2002). The study objectives were to (1) determine the impact of pesticide use on avian reproduction by comparing reproductive success between birds foraging on pesticide-treated and reference test sites; (2) monitor avian dietary exposure to pesticides; (3) monitor avian brain cholinesterase (ChE) activity indicative of exposure to carbamate and organophosphate

(OP) insecticides; and (4) document any mortality or other adverse effects that may be related to pesticide applications on the refuge.

Methods

Pesticide Use

We calculated numbers of pesticide applications and products used/plotted at the end of each growing season from pesticide use records kept by the USBR.

Avian Reproductive Success

1) Kestrels. We placed 20 nest boxes throughout agricultural lease lands on Tule Lake NWR (pesticide-treated plots) and 10 boxes on Lower Klamath NWR (reference plots) in 2002 and 2003. The kestrel boxes were constructed of 10-in. diameter PVC pipe, 18 in. long. The box floors were ¾-in. pine, the lids were 1½-in. redwood, and each box contained one 3-in. entry hole. The boxes were each attached to a metal pole suspended approximately 4 m off the ground, facing northeast. We placed nest boxes at a density of < 1 box/2.5 km^2 to minimize intraspecific competition between nesting pairs. All nest boxes were located more than 1600 m from cultivated fields off-refuge to minimize exposure of birds to pesticides not approved for refuge use.

2) Starlings. We erected starling nest boxes on seven pesticide-use plots and seven reference plots in 2002 and 2003. The boxes were constructed of 1-in. x 8-in. wooden planks. Each box contained a 2.5-in. entry hole and was constructed to the following dimensions: 18 in. (height) x 8 in. (width) x 4 in. (depth). They were attached to a metal pole and suspended approximately 2 m off the ground. A row of 20 nest boxes was placed on each test plot with a northeast orientation and separated at intervals of approximately 20 m. We selected test plots based on accessibility and the presence of starlings. All pesticide-treated plots were located on Tule Lake NWR lease lands in areas known as Sump 2 and Sump 3. Reference plots were located in areas that were not expected to receive frequent applications, including areas immediately adjacent to lease lots with organic certification and cooperative farming leases. All seven reference plots were placed adjacent to small grain fields on Lower Klamath Refuge in 2002. Three reference plots were located adjacent to co-op grain fields at Lower Klamath Refuge, and four reference plots were located adjacent to certified organic alfalfa plots at Tule Lake Refuge in 2003. All nest boxes were located more than 1600 m from

cultivated fields off-refuge to minimize exposure of birds to pesticides not approved for refuge use.

3) Nest Monitoring**.** Nest box status was assessed for each box 2-3 times/wk for the duration of nesting activity, typically April-July of each year. Boxes were monitored to record (1) nest condition, (2) number of eggs present, (3) number of nestlings present, (4) number of dead nestlings present, (5) hatching events, (6) samples taken, and (7) other observed activity.

Dietary Exposure to Pesticides

We used esophageal constriction to collect composite dietary samples from each clutch 9-12 d after hatching. Pipe cleaners were secured around the neck of each nestling to restrict food intake and left in place for 1 hour before noon, during the peak of parental foraging efforts. Samples were removed from the nestlings' crops using forceps and sealed in sampling containers. Forceps were cleaned with soap and water and a rinse of methanol after each use. Samples were placed in a cooler on wet ice in the field and transported to the lab where they were stored in a freezer at -20°C until they could be shipped to Mississippi State Chemical Laboratory for analysis. We were unable to coordinate sampling events with pesticide applications because we did not know in advance what applications were planned for each test plot; we therefore compared sampling events to the location and timing of pesticide application reports at the end of the growing season to determine which samples to submit for residue analysis. All chemical analyses were performed by Mississippi State University following standard protocols (Shafik et al., 1973; USEPA, 1980).

Brain Cholinesterase Sampling

1) Incidental Mortalities**.** We collected all birds and mammals found dead on the study site for possible analysis of pesticide exposure. We externally evaluated each bird carcass and noted presence or absence of any physical anomalies or trauma, then double-bagged the carcasses with labels indicating the sample number and time and location found, and placed them on wet or dry ice in the field for transportation the field station freezer. Brains were collected from suitable specimens for determination of brain ChE activity.

2) Sacrificed Nestlings**.** We euthanized starling nestlings before they left the nest in order to evaluate the occurrence of organophosphate and carbamate-induced brain

cholinesterase depression. The nestlings were sacrificed between the ages 15-18 d according to established protocols. Nestlings are essentially fully feathered by that time, although feathers would ordinarily continue to develop until the fledglings leave the nest at 21 d (Kessel, 1957). Euthanasia was performed by CO_2 asphyxiation using the dry ice method. Each nestling was taken out of the nest box and placed in a cooler. The bottom of a tall cup was filled with dry ice shavings and placed inside the cooler with the nestlings. Water was then poured onto the dry ice and the lid of the cooler positioned atop. Sacrificed birds were then labeled, double-bagged, and placed directly on dry ice until they could be placed within the lab freezer at -20°C.

3) Analyses. We shipped all samples on dry ice to the Institute of Environmental and Human Health at Texas Tech University for determination of ChE activity and carbamate and organophosphate inhibition using reactivation methods (Gard and Hooper, 1993; Hunt and Hooper, 1993). Percent reactivation of total ChE by EDTA ≥10% was considered diagnostic of carbamate exposure. Percent reactivation of total ChE by 2-PAM ≥5% was considered diagnostic of organophosphate exposure. Minimum percent inhibition ≥50% was considered diagnostic of death by pesticide poisoning (Ludke et al., 1975).

Habitat Assessment

We conducted 24 surveys of habitat use by adult starlings in 2003 to verify the assumption that feeding activity would be primarily restricted to habitats immediately adjacent to the nesting structure (Kessel, 1957). For each survey, observers monitored active nest boxes during morning feeding periods from a distance of approximately 50 m. They recorded the terminal location of each foraging sortie by adult birds leaving the nest boxes. Location information included the habitat type (non-crop, small grain, row crop, or alfalfa) and distance from the nest box (0-100 m, 100-200 m, or >200 m).

Data Compilation and Analyses

We entered all field and lab data into Microsoft Excel spreadsheets. These files contained starling and kestrel nest-box monitoring data, pesticide applications on Tule Lake NWR lease lands, starling sexes and masses, dates of food and fledgling sample collection, and Environmental Contaminant Data Management System (ECDMS) catalogs. Statistical analyses were performed using STATISTICA version 7. Alpha <0.05 was considered significant.

We examined the following reproductive parameters: number of nests, number of eggs, clutch size (calculated as number of eggs/nests), percent hatch (calculated as number of eggs hatched/clutch size), percent fledge (calculated as number of young fledged/number hatched), and number of fledges/nest (calculated as clutch size * % hatch * % fledge). We compared reproductive parameters to habitat variables including the year of investigation, the site in which nesting boxes were located (for purposes of coding, Tule Lake NWR pesticide and non-pesticide locations were coded as different sites), presence or absence of pesticide use, number and type of pesticide applications, predominant crop in the vicinity of each starling nesting-box plot, and distance (km) of nest-box plots from the east slope of Sheepy Ridge. Sheepy Ridge, which runs north-south between Lower Klamath NWR to the west and Tule Lake NWR Sumps 2 and 3 to the east, provides starlings with natural nesting cavities and was considered a source of birds to populate test-plot nest boxes.

We coded the year, site, treatment, and crop type in order of fledges/nest from lowest to highest for multiple regression analyses, evaluating relationships of reproductive parameters to habitat variables (Table 1). We used this coding system because we considered the number of fledges/nest to integrate any effects on clutch size, percent hatch, and percent fledge.

Results

Pesticide Use

Pesticide use on reference and pesticide-treated plots is summarized in Table 2, which shows the number of applications and products applied in both years. Of the reference plots located at Lower Klamath NWR, 2,4-D was applied to plots LK-05 in 2002 and LK-01 in 2003. No other pesticide use was reported for reference plots at Lower Klamath or Tule Lake NWRs. Predominant crop types are shown in Table 3.

Avian Reproductive Success

1) Kestrels**.** Kestrel nest-box occupancy was limited due to competition from starlings. Although field crews attempted to keep the boxes clean of starling nests, kestrels used only one of the 30 kestrels boxes monitored in 2002. An adult female with two eggs was

located in a pesticide-treated plot on Tule Lake NWR Sump 2 in late May. The nest ultimately produced a clutch of four eggs, but neither eggs nor nestlings were present when the box was checked in late July, and the nest remained inactive for the duration of the study. Kestrels initiated two nests in boxes in pesticide-treated plots in 2003. On Tule Lake NWR Sump 2, a nest produced five eggs. All five eggs hatched and three of five nestlings survived to fledge. A nest in Tule Lake NWR Sump 3 was also successful; four of five eggs laid in this nest hatched, and all four hatchlings survived to fledge. This limited kestrel breeding activity precluded statistical analyses and will not be further discussed.

2) Starlings**.** Starling reproductive success is summarized in Table 4. Statistical comparisons between reproductive parameters and habitat variables were as follows:

Number of Nests and Eggs. The number of nests/plot ranged from 0.00-41.00; number of eggs/plot ranged from 0.00-208.00. Values were log10-transformed for data analyses because both number of nests and number of eggs were log-normally distributed. In main-effects ANOVAs, numbers of nests were significantly different by both year and distance interval from Sheepy Ridge, with significantly fewer nests in 2003 ($F(1,23)= 35.197$; $p<0.001$) and fewer nests with increasing distance from Sheepy Ridge ($F(3,23)= 11.765$; $p<0.001$). Differences in number of nests by pesticide treatment and crop type were not significant when included in main-effects ANOVA with year and distance interval ($p=0.879$ and $p=0.148$, respectively). Statistical results for the number of eggs (not shown) were similar to those for the number of nests due to the strong positive correlation between those parameters.

Clutch Size. The overall clutch size/plot ranged from 2.33-5.50 eggs. Clutch size was not significantly correlated (Pearson's r) with any treatment or habitat variable. In a main-effects ANOVA examining the year, site, treatment, and distance from Sheepy Ridge, only the year was significant ($F(1,20)=34.493$; $p=0.047$), with larger clutches in 2002 than in 2003.

Percent Hatch. Percent hatch ranged from 0.31-0.90. Percent hatch was not significantly correlated by Pearson's r with number of eggs, number of nests, or clutch size. Percent hatch was positively correlated with crop type ($r= 0.555$; $p=0.003$) and negatively correlated with the number of pesticide applications ($r= -0.492$; $p=0.011$), number of insecticide applications (*r*= -0.456; *p*=0.019), number of herbicide applications (*r*= -0.469; *p*=0.016), and number of fungicide applications (*r*= -0.428; *p*=0.029), all of which co-varied. In forward step-wise multiple regression analyses, crop type and number of fungicide applications entered the regression significantly (adj. r^2= 0.391; $F(2,23)$=9.015; *p*=0.0012). Although the total number of pesticide applications could be substituted successfully in the regression equation, it explained slightly less variability. The semi-partial correlation coefficients for crop type and number of fungicide applications were 0.505 and -0.361, respectively.

Percent Fledge. Percent fledge ranged from 0.15-1.00. Percent fledge was not significantly correlated by Pearson's *r* with number of eggs, number of nests, or percent hatch. However, percent fledge was significantly negatively correlated with clutch size (*r*= -0.396; *p*=0.045). Percent fledge did not correlate significantly with any treatment or habitat variable. Its strongest correlation was with year (*r*= 0.332; *p*=0.098). Mean percent fledge was lower in 2002 than in 2003.

Fledges/Nest. Number of fledges/nest ranged from 0.43-4.00, and was highly correlated with percent hatch (*r*=0.747; *p*<0.001), but less highly correlated with percent fledge (*r*=0.449; *p*=0.021). Like percent hatch, fledges/nest was positively correlated to crop type (consistent with the manner in which crop type was coded); however, negative correlations with numbers of pesticide applications were not significant. In addition, no other habitat or treatment effects were significantly different by *t*-test, ANOVA, or multiple regressions.

Dietary Sampling

Of 122 starling dietary samples that we collected during 2002 field activities, we submitted 44 samples for pesticide-residue analysis. In 2003, we submitted 27 samples from starling nestlings and three samples from kestrel nestlings for pesticide-residue analysis. Starling samples were primarily composed of insect material. The kestrel samples contained a variety of animal material including insect, small mammal, and lizard. Analytical results are summarized in Table 5. The most commonly detected pesticides were dicamba, a benzoic acid herbicide, and 2,4-D, a phenoxy herbicide.

Brain Cholinesterase Activity

1) Incidental Mortalities. Brain ChE levels were determined for 72 starling nestling carcasses collected in 2002 and 17 recovered in 2003, including two broods of three and four nestlings, respectively, found dead on reference plots.

2) Sacrificed Nestlings**.** Brain ChE analysis was conducted on 205 sacrificed nestlings in 2002 and 151 in 2003.

3) Combined Results. Results for both collected and sacrificed nestlings are summarized in Table 6. There was evidence of limited exposure to both OP and carbamate pesticides. However, percentages of exposed birds were low (with the possible exception of collected carcasses on reference sites in 2003), and minimum percent inhibition in all recovered carcasses and sacrificed nestlings was below the 50% threshold used to diagnose pesticide poisoning as the cause of death. In addition, no external abnormalities were observed in any nestlings that would suggest a cause of death.

Habitat Assessment

We evaluated foraging distances of adult starlings from the nest boxes in a one-way ANOVA using the number of birds/survey observed to forage at 0-100 m, 100-200 m, and >200 m from nest boxes at four sites. The number of birds foraging within 100 m of the nest boxes was significantly greater than the number foraging between 100-200 m and beyond 200 m (Table 7). Eighty-two percent of birds foraged within 200 m of their nest boxes. However, approximately 18% of the sorties extended to locations >200 m from the nest. Observers often lost sight of birds at distances >200 m; therefore, it was not possible to document the maximum distances of those sorties.

Discussion and Management Recommendations

Avian Reproductive Success

We attempted to use a systematic approach to separate pesticide or other habitat effects on avian reproduction from natural variation by preferentially selecting areas most likely to receive pesticide applications (e.g. row crops). However, at the time of nest-box placement, it was often not clear what crops would be planted adjacent to the study plots. Consequently, although the majority of nest boxes on both treatment and reference areas were located adjacent to cereal grains, crop diversity was greater on treatment plots than on reference plots. Pesticide-treated plots included onions, potatoes, and alfalfa, as well as small grains. Reference plots were limited to alfalfa and small grains because there were no onion and potato fields that met the reference criteria of minimal pesticide use. Additionally, we had no control over which pesticides were applied, when they were applied, or where they were applied. Lessees were free to apply pesticides at their own discretion within the limitations of the refuge pesticide-use restrictions. In spite of these difficulties, we observed several patterns in starling productivity.

Starling nesting activity varied from site to site, with nest boxes having full occupancy at some sites and no occupancy at others. We found no statistically significant correlations between pesticide use and overall starling productivity as measured by numbers of nests and eggs. Numbers of nests and eggs showed strong negative relationships with distance from the natural nesting areas on Sheepy Ridge. This might represent an effect related to dispersal distance from Sheepy Ridge and site fidelity of breeding female starlings, and our results suggest that the nest boxes in agricultural fields were less suitable breeding habitat for starlings than the nesting areas on Sheepy Ridge. However, after adjusting statistically for distance from Sheepy Ridge, there was still a significant reduction in the number of nests in 2003 compared to 2002. Possible causes for this difference include (1) natural variation related to weather. Spring conditions in 2003 were wetter and cooler than in 2002 (IREC, 2005), which could suppress or delay breeding activity (Kessel, 1957); (2) localized impacts in 2003 from collecting all nest-box fledglings in 2002 (Kessel, 1957; Cabe, 1993).

Of the three parameters used to calculate number of fledges/nest, only percent hatch showed any correlation to pesticide use patterns. Mean clutch size and percent fledge in test plots were within the ranges of values previously reported for other starling populations (Kessel, 1957, Cabe, 1993). The negative correlation between clutch size and percent fledge, also observed by Kessel (1957), suggests a possible compensatory mechanism by which number of fledges/nest is maintained by higher fledging success when clutch sizes are lower. Such a mechanism could be mediated by decreased energetic demands being placed on parents with smaller clutches, resulting in a higher level of parental care/fledgling.

Mean percent hatch was lower than reported for other populations, for which literature values averaged about 91% for first clutches and 81% for second clutches (Kessel, 1957; Cabe, 1993). Percent hatch showed a positive correlation with grain-type crops and alfalfa, and a negative correlation with the number of fungicide applications in the test sites (or total number of pesticide applications). The lowest hatching success was in potatoes, which also receive the most pesticide applications. However, the number of pesticide applications/month (Table 8) tends to peak in mid- to late summer, while the starling incubation period occurs in late spring to early summer, suggesting that the relationship between percent hatch and pesticide use might be correlative only due to co-variance of number of pesticide applications with crop type. We plan to further evaluate this relationship. The mean numbers of fledges/nest in this study were within the lower range of values reported by Kessel (1957), who found an average of 3.77 (s.d.±1.12) fledges/nest in first clutches and 3.30 (s.d.±1.48) in second clutches.

Pesticides in Avian Diet

Our analyses of starling and kestrel food items confirm several incidents of pesticide exposure. Although the detected concentrations were below known acute or chronic thresholds (USEPA, 2001), our ability to determine maximum concentrations of pesticides in dietary samples might have been impaired due to lack of correspondence between sampling events and application activities. Since we did not have access to application schedules, we compared pesticide-use information to sample collection dates and locations at the end of the growing season to decide which chemicals to screen and which samples to submit. We preferentially selected samples for analysis based on the location and timing of application events, but it was not always possible to match samples to a 24-hr window following pesticide application. This could have caused us to underestimate exposure, since modern pesticides are rapidly degraded in the environment.

Dicamba and 2,4-D were the most common pesticides detected in food items during both study years. Several products containing these pesticides are approved for use on the refuges. However, several pesticides were detected in nestling diets that are not permitted on the refuges. These included 2,4-DB, aldicarb, carbofuran, propazine, simazine, and dichlorprop.

While the presence of such chemicals suggests noncompliance with refuge pesticide restrictions, other scenarios are possible. Nestlings could be exposed to pesticides used off-refuge if parents brought food from those locations back to the nest. Although we observed that most adult starlings foraged within 100 m of their nest boxes, consistent with Kessel (1957), 18% of the foraging sorties extended beyond 200 m. Therefore, it is possible that exposure to restricted pesticides occurred from applications off-refuge, even though we located starling nest boxes >1600 m from private lands specifically to reduce the likelihood that parents would forage off site.

In addition, there are several pathways by which adult birds foraging within the test plots could be exposed to pesticides used off site. Examples include (1) movement of insects treated off site to the federal lease lands; (2) aerial drift (Fletcher et al., 1994; Teske et al., 2001); (3) irrigation water, for example, the Tule Lake NWR lease lands are geographically located at the end of the regional irrigation supply, and low levels of pesticides have been previously been detected in irrigation water on the refuge (Sorenson and Schwarzbach, 1991); (4) cultural practices, such as failure by applicators to clean equipment properly following applications off-refuge, or use of seed potatoes with aldicarb residues; and (5) false positives associated with laboratory analysis; however, reported quality assurance and quality control procedures did not identify any cross-contamination problems with the analysis.

Biomarker of Pesticide Exposure in Nestlings

Analyses of brain cholinesterase activity showed that a small percentage of nestlings were exposed to OP and carbamate insecticides in both reference and pesticide- treated plots. The data for cholinesterase reactivation suggests that exposure to carbamate pesticides is greater in collected carcasses (birds found dead during nest monitoring activities) than in sacrificed nestlings. However, the level of cholinesterase inhibition observed in these individuals was <50%, the level typically used to confirm pesticide exposure as the cause of death (Ludke et al., 1975).

We collected the carbamate-inhibited samples prior to the known application dates of the carbamate insecticide carbaryl on the refuges. Therefore, reported uses of pesticides do not explain the observed carbamate inhibition, which might be related to pesticides used off-refuge. The observed OP inhibition, however, overlapped reported uses of chlorpyrifos, malathion, and disulfoton.

Management Recommendations

Our results suggest that refuge management tools seem to be effective at reducing wildlife losses to pesticides and should be continued. However, several observations suggest possible violations of the pesticide approval and reporting process, as well as uses prohibited by state and federal law. Managers should work with county regulatory agencies to ensure that pesticide uses on refuges are appropriate to goals of the Klamath NWR Complex.

Our results further suggest that starling productivity could be enhanced by managing the types of crops and numbers of pesticide applications made on refuge lands during the growing/breeding season. While these results might be unique to starlings (an exotic species not generally of management concern), they could also apply to other cavity-nesting or ground-nesting bird species that are of management concern and have shown preferential use of specific types of crops (Thomson, 2003). However, we need to evaluate the relationship between hatching success and fungicide applications in more detail to decide whether it is merely correlative.

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Table 1. Mean fledges/nest (±s.d.; n) by year, site, pesticide treatment, and crop type. Code indicates coded value for each variable used in multiple-regression analysis.

Variable	Fledges/Nest	Code
a. Year		
2002	2.069 (±0.806; 14)	1
2003	2.213 (±0.820; 12)	2
b. Site		
Tule Lake Sump 2 (1-pesticide)	1.909 (±0.916; 5)	1
Lower Klamath Lake	1.976 (±0.741; 9)	2
Tule Lake Sump 2 (2-reference)	2.224 (±0.937; 8)	3
Tule Lake Sump 3	2.446 (±0.628; 4)	4
c. Pesticide treatment.		
Pesticide	2.118 (±0.906; 13)	1
No pesticide	2.121 (±0.718; 13)	2
d. Crop type		
Potatoes	1.240 (------; 1)	1
Barley	1.643 (±1.242; 3)	2
Onions	1.741 (±0.347; 3)	3
Marsh/Grain interface	1.976 (±0.741; 9)	4
Alfalfa	2.420 (±0.547; 5)	5
Wheat	2.766 (±0.794; 5)	6

Table 2. Number of pesticide applications by type/number of products, and predominant products used on reference and pesticide treated plots on Lower Klamath and Tule Lake National Wildlife Refuges in 2002 and 2003.

Year	Site	Fungicides/fumigants	Herbicides	Insecticides
2002	Reference	0/0	1/1 2,4-D (amine)	0/0
	Pesticide	21/7 Mancozeb Chlorothalonil	25/9 2,4-D (amine) Dicamba	9/4 Malathion
2003	Reference	0/0	1/1 2,4-D (amine)	0/0
	Pesticide	18/6 Mancozeb Chlorothalonil	44/11 Oxyfluorfen Glyphosate	16/6 Permethrin Malathion

Table 3. Predominant crop types in reference and pesticide-treated plots by percentage of total plots planted. N=7 in all four sites. Twenty-eight percent of reference plots were not cultivated in 2002.

Year	Site	Row Crops	Grain	Alfalfa
2002	Reference	0%	72%	0%
	Pesticide	30% Onions and Potatoes	60% Wheat and Barley	10%
2003	Reference	0%	43%	57%
	Pesticide	67% Onions and Potatoes	33% Wheat	0%

Table 4. Mean (±SD) starling reproductive success in reference and pesticide-treated plots in 2002 and 2003. N=number of active nests. Clutch size=number of eggs/nest. Percent hatch=(number of eggs that hatch/clutch size). Percent fledge=(number of hatchlings that survive to fledge/number eggs that hatch). Fledges/Nest=(clutch size*% hatch*% fledge). Mean values from the birds of North America (BNA) species account (Cabe, 1993) are provided for comparison. BNA means are combined means and SDs for first and second clutches.

Year	Site (N)	Clutch Size (SD)	% Hatch (SD)	% Fledge (SD)	Fledges/Nest (SD)
2002	Reference (90)	4.61 (±0.45)	0.63 (±0.02)	0.71 (±0.03)	2.15 (±0.23)
	Pesticide (172)	4.37 (±0.46)	0.62 (±0.03)	0.75 (±0.03)	1.99 (±0.31)
2003	Reference (51)	4.01 (±0.66)	0.69 (±0.02)	0.84 (±0.03)	2.09 (±0.66)
	Pesticide (25)	4.31 (±0.50)	0.56 (±0.03)	0.90 (±0.02)	2.21 (±0.28)
BNA		4.45	0.87 (±0.06)	0.88 (±0.05)	3.53 (±0.33)

Table 5. Concentrations of pesticides detected in starling dietary samples in 2002 and 2003. Concentrations of detected pesticides were below acute and chronic threshold concentrations.

Analyte	2002		2003	
	N (of 44)	Conc. (ppm dw)	N (of 27)	Conc. (ppm dw)
2,4-D	11	0.424 - 7.49	2	0.923 – 1.51
2,4-DB[a]	3	0.248 – 0.642	1	0.453
Aldicarb sulfoxide[a]	3	0.340 – 0.410		
Carbofuran 3-OH[a]	1	0.272		
Propazine[a,b]	9	0.376 – 1.25		
Simazine[a]	5	0.427 – 0.699	1	0.453
Dicamba	13	0.053 - 0.360	4	0.075 – 0.094
Dichlorprop[a]	6	0.060 – 3.81	3	0.75 – 0.092

[a]Not approved for refuge use.

[b]Not approved for use in California and Oregon.

Table 6. Comparisons by year of number and percent of sacrificed nestlings vs. collected carcasses showing ranges of cholinesterase reactivation and inhibition indicative of exposure to organophosphate or carbamate pesticides on reference sites vs. pesticide-use sites.

				OP Exposure			Carbamate Exposure		
Year	Type	Treatment	Total N	n (%)	Reactivation	Inhibition	n (%)	Reactivation	Inhibition
2002	Sacrificed	Reference	90	1 (1%)	5.1%	4.9%	0 (0%)	-----	-----
		Pesticide	115	5 (4%)	5.2-10.0%	5.0-9.1%	0 (0%)	-----	-----
	Collected	Reference	20	0 (0%)	-----	-----	1 (10%)	13.1-13.2%	11.5-11.6%
		Pesticide	52	0 (0%)	-----	-----	5 (10%)	11.1-14.2%	10.0-12.5%
2003	Sacrificed	Reference	109	1 (1%)	7.1%	6.65%	2 (2%)	12.2-15.5%	10.9-13.4%
		Pesticide	42	0 (0%)	-----	-----	0 (0%)	-----	-----
	Collected	Reference	13	0 (0%)	-----	-----	6 (46%)	11.3-20.8%	10.2-18.3%
		Pesticide	4	0 (0%)	-----	-----	0 (0%)	-----	-----

Table 7. Results of one-way ANOVA for number of bird/survey foraging in 100-m increments from their nest boxes.

Variable	SS	v	MS	F	p
Increment	6.354	2	3.177	12.336	0.002
Error	2.317	9	0.257		

Tukey's Honest Significant Difference[a]

Increment	0-100 m[a]	100-200 m[b]	>200 m[b]
Mean birds/survey	2.14	0.84	0.44

[a]Sites with a common letter cannot be differentiated by the test.

Table 8. Number of pesticide applications by type and month (both years combined).

	Number of Applications		
Month	Fungicides/Fumigants	Insecticides	Herbicides
April	2	4	2
May	0	1	21
June	9	9	35
July	14	13	4

AGGREGATE COSTS AND BENEFITS OF GOVERNMENT INVASIVE-SPECIES CONTROL MEASURES IN CALIFORNIA

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Abstract

Policies related to the introduction and spread of harmful nonindigenous invasive species is central to biosecurity. Such policies include government activities undertaken to exclude, detect, eradicate, contain, and suppress invasive species that affect agriculture. We identify and measure costs of government activities attributable to invasive-species management in California agriculture. We also explore potential economic costs from curtailing these activities, thereby increasing probability and severity of pest or disease occurrences. Potential loss in consumer and producer benefits from agricultural production is roughly proportional to the value of output, depending on relevant supply-and-demand relationships. Many invasive species have potential impacts on the nonagricultural environment, but evaluation of these broader ecosystem consequences is left for further research. We compare our measures of economic losses from agricultural invasive species that would follow from removal of government control programs to direct costs incurred in government programs for control of invasive species. We find that costs of increased probability and severity of pest occurrences far exceed recent government budget outlays to protect against such occurrences. The benefit-cost ratios are generally greater than 3:1 and often greater than 5:1.

Key words: invasive species, agricultural pest management, biosecurity

Introduction

This paper summarizes costs and provides estimates of benefits from government activities to control invasive pests and diseases that may affect California agriculture. Our research has developed data on costs of government activities undertaken to exclude, detect, eradicate, contain, and suppress exotic pests and diseases. We also explore potential economic costs that would occur as a result of dropping these government activities and thereby increasing the probability and severity of pest or disease occurrences. The benefit-cost ratios are simulated approximations based on historical data on government costs and simulated benefits.

We have identified government activities and costs attributable to exotic pest and disease management activities in California, including those by the California Department of Food and Agriculture and the federal government, including the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS), the USDA

Commodity Credit Corporation, and activities assumed by the Department of Homeland Security (Kreith, 2004). By exotic pests, we refer to invasive species, nonindigenous, non-native, and foreign species (including animal or plant diseases and noxious weeds) that cause harm to agriculture and often beyond agriculture.

We also compiled a list of possible industry-pest combinations and a list of significant agricultural economic activities at risk. Benefits to producers and consumers from pest and disease management activities and programs can be quantified to the extent these activities prevent occurrences of economic impacts. Some industry-pest combinations include citrus canker for oranges and lemons, exotic Newcastle disease for poultry, foot and mouth disease for dairy and beef, and glassy-winged sharpshooter for grapes.

Our research did not undertake an assessment of the success or efficiency of particular programs or agencies, nor is it an assessment of the costs of specific pests or host-pest combinations. Rather, the intent is to determine the economic contribution of state and federal government invasive-species activities in California.

Summary of Methodology

We reviewed major invasive pests and diseases facing California agriculture and the major commodities at risk. We related these risks to the value of farm output (indicated by cash receipts) to determine the potential value of output affected. Potential losses to consumers and producers are roughly proportional to the value of output, depending on the relevant supply-and-demand elasticities. Losses to farmers, represented by unrealized producer net gains, depend on added per-unit costs of production including loss of yields or output. The more elastic the supply-and-demand functions for the commodity affected, the smaller the net gains relative to total revenues. For California crops or livestock industries as a whole, the supply is relatively inelastic with respect to a overall changes in prices of farm output, meaning aggregate production falls relatively little if the aggregate price of agricultural output declines. Alternatively, the supply of an individual commodity, say alfalfa hay, may be more responsive to a change in its own price as farmers move to substitute alternative crops as the price of a single crop falls. Demand facing California agriculture as a whole also is relatively inelastic, whereas the demand for a single crop would be more elastic as consumers shift between items when relative prices change. Producers gain from higher market prices, but consumers lose from these same price increases.

Some public outlays may be considered investments to reduce cost of future pest incursions; other outlays deal with current pests. Past investments affect current reduced probabilities of incursions, or reduce their severity and are balanced by current investments that have future payoffs. Thus with a continuing stream of investments (assuming a steady state), we consider the payoffs as a current stream of costs compared to the current stream of benefits.

Results of these considerations are that benefits of government outlays have a relatively simple formulation, and many complications may be relatively unimportant for broad approximations. The value at risk and the proportional expected value of that loss can determine potential losses if pest outbreaks occur.

Costs of Government Programs for Protection From and Control of Exotic Pests and Diseases Affecting Agriculture

Many pests and diseases affect California agriculture, and some of those are exotic in the sense that they may enter from elsewhere and cause harm. Table 1 lists some significant pests and some of the major commodities they affect. While costs for control of indigenous pests are in general borne by the private sector, activities undertaken to control invasive, non-indigenous pests and diseases are typically an expense to taxpayers.

Based on an extensive survey of budget documents and information supplied by state and federal government program managers, we have compiled expenditure outlays on government exotic pest-control activities in California. Our expenditure database is unique in that expenditures were further categorized as exclusion, detection, or containment/suppression/ eradication activities.

Roughly $450 million was spent by the state and federal governments on the control of exotic pests and diseases of agricultural plants and animals in California during the 2003 state and federal fiscal years. (California state expenditures for the July 1, 2002, through June 30, 2003, the state fiscal year, have been combined with federal expenditures for October 1, 2002, through September 30, 2003, the federal fiscal year.) California state expenditure for exotic pest and disease exclusion, detection, eradication, and control was approximately $128 million. Federal expenditure was approximately $321million (Table 2).

Table 2 also provides a breakdown of government outlays in California on exotic pests and diseases. Not counting expenses to control exotic Newcastle disease (END) and Pierce's disease (PD), and the glassy-winged sharpshooter (GWSS), an important insect vector for the viral Pierce's disease, California spent $22.3 million to control exotic pests and diseases of animals and $85.9 million to control plant pests and diseases. Not counting expenditures on END, the federal government spent another $1.8 million in California on the control of exotic pests and diseases of animals, and $138.7 million on the control of plant pests and diseases during federal fiscal year 2003.

As Table 2 shows, a large share (44%) of government expenditures on the control of exotic pests and diseases in California in the fiscal 2003 periods was attributable to programs controlling END and PD and GWSS. The (mainly federal) government costs of the successful eradication of END alone accounted for 37 percent of the total.

Table 3 further separates animal-related outlays by type of control activity. Of the $25.1 million in state outlays spent to control pests and diseases of animals; exclusion activities accounted for $5.2 million; detection $15.9 million; and activities associated with containment, suppression, or eradication accounted for $4.3 million. Of this last category, END efforts comprised $2.7 million. All but $1.8 million in federal outlays were devoted to the END effort and almost all of that, $161.6 million, was categorized as eradication.

Eradication of END used $3.4 million from the USDA-APHIS Veterinary Service, plus $161.6 million in federal emergency funds from USDA Commodity Credit Corporation during fiscal 2003. As the Table 3 documents, this was 99 percent of all federal expenditures used to control exotic pests and diseases of animals in California during the federal fiscal year. That eradication also demanded the depopulation of more than 3 million birds. In addition, CDFA spent $2.7 million on END, about 11 percent of its fiscal 2003 budget, to control exotic pests and diseases of animals. END is a fatal viral disease that affects all bird species. END was first detected October 1, 2002, in Southern California backyard poultry before spreading to commercial operations in the state and to flocks in Nevada, Arizona and Texas. It was totally eliminated in California and the other states by September 2003.

Eradication was achieved by quarantines combined with depopulation and extensive surveillance and laboratory detection. Benefits of this eradication program clearly extended beyond commercial agriculture.

As Table 4 documents, outlays in California for plant-related, pest-control activities were less concentrated on a single pest or disease than was the situation with animal protection expenditures in 2003. Not counting PD and GWSS eradication, and suppression costs, $8.6 million of state expenditures on plant pest and disease control were focused on exclusion activities, $46.7 million on detection, $23.3 million on eradication and $7.1 million on suppression activities. Again excluding the outlays on PD and GWSS, the federal expenditure of $138.7 million on plant pests and diseases consisted of $123.3 million for exclusion, $15.4 million on detection, and less than $0.2 million on management and suppression activities.

The GWSS can rapidly spread PD, which kills grapevines and affects 460 other plant species, native and non-native. Discovery of a single GWSS in California in 2000 led to major government efforts to contain that plant disease and eradicate or contain its insect vector. The state spent $17.4 million on the Pierce's Disease Program between July 1, 2002, and June 30, 2003, not counting industry assessments for research. This represented 17 percent of CDFA expenditures for control of invasive plant pests and diseases. USDA-APHIS spent $15.6 million for PD and GWSS control in California between October 1, 2002, and September 2003, accounting for 10 percent of the federal expenditures in California on control of exotic plant pests and diseases.

Total government outlays on agricultural invasive-species control activities in California equaled approximately 1.7 percent of the $27 billion value of cash receipts for all California agriculture during 2003. State expenditure on pest control equals 0.45 percent of the value of California agricultural cash receipts. Federal outlays in California related to pests of California commodities were higher than state outlays, primarily due to the cost of eradicating END that occurred during the period studied. We note that, in addition to benefits to California agriculture, those outlays benefit the natural ecosystem, consumer interests, and human health, as well as agriculture in states other than California. That is, federal programs that take place in California do not just benefit agriculture in California. (At the same time federal expenditures that are not directly connected to California programs also benefit California.)

Approach To Assessing Costs of the Increased Likelihood and Severity of a Pest Occurrence

To assess impacts on costs and benefits, we consider how supplies of and demands for important commodities may be affected by exotic agricultural pests and diseases.

Government exotic pest outlays are designed to reduce the probability of a pest occurrence through pest exclusion and detection programs, and to reduce the impacts of an occurrence through monitoring, containment, eradication, and suppression. One value of these programs may be calculated based on the impact that they have on the expected value of supply-and-demand for affected commodities. The expected value of the impact of an occurrence is equal to the probability of a supply or demand shock multiplied by the magnitude of the shock, given that one occurs. The benefit of the policy is calculated as the difference in the expected values with and without the policy in place. For example, consider a program that reduces the probability of a pest infestation from 20 percent to 5 percent. Assume also that the program reduces the supply impact or severity of an infestation from a 30 percent shift back in supply to a 10 percent shift back in supply. In this case, the expected value of a supply loss with no program is (0.20) times (30%) or 6 percent. The expected value of a supply loss with the program in place is (0.05) times (10%) or 0.5 percent. The difference of 5.5 percent gain in expected supply (6.0% - 0.5%) represents the value of the government efforts to control invasive species through exclusion, detection, and containment/eradication programs. A similar set of considerations may be applied to the demand shifts.

In our simulation models, we represent the effects of discontinuation of government outlays on exotic pests and disease policies by the differences in the expected impacts of pest occurrences with and without the programs. Thus, when we show an effect on supply of 5 percent, this represents the combination of effects on the probabilities of an occurrence and the severity of the occurrence.

The simulation model is a simple mathematical representation of the concepts in Figure 1. In Figure 1, we show a shift back in the supply function from S_0 to S_1 for a

California commodity caused by an exotic pest occurrence. At the same time, the infestation causes international demand to shift back from DX_0 to DX_1 and total demand, the sum of international and domestic demand, shifts back from D_0 to D_1. The result in this example is no change in the market price (a special case) and a decline in quantity sold from Q_0 to Q_1.

We specify approximate long-run supply-and-demand parameters for California agriculture as a whole, and for 10 important commodities in the state. We specify demand elasticities for the domestic and international markets and overall supply elasticities for each of these 10 commodities and for California agriculture as a whole, and each commodity's share of export and shipments to the domestic market. The demand elasticities are taken from the economic literature, considering the market shares of California commodities and the potential substitutes for California farm output. Long-run supply elasticities incorporate the potential to substitute across crops in response to commodity-specific pests that may raise costs.

Table 5 provides an overview of gross receipts for California agriculture as a whole and for each of the top 10 commodities by gross receipts. Table 5 also includes the share (by weight) of international exports for each commodity. These export shares are used to weight the demand effects and to determine the share of costs borne by domestic and foreign consumers. Table 6 shows the demand and supply elasticity parameters used in the model. These are long-run parameters that reflect market adjustments that could be expected if a pest outbreak were to occur and persist.

We next must specify the differences in the expected supply-and-demand shocks that would be imposed by the removal of the government activities now used to control invasive species. We can then solve for the new equilibrium prices and quantities, and consider how the actions of public pest and disease programs influence the probability and severity of an occurrence.

From the impacts on prices and quantities, we may calculate the effects on producer and consumer benefits. These benefit measures depend on the position and shape of the demand and supply functions. Shifts in these functions, as a consequence of an exotic pest occurrence, produce a new equilibrium of prices and quantities and, therefore, new consumer and producer benefits. We calculate the difference in benefits to consumers and producers under the alternative assumptions of pest-infestation probabilities and severities that would occur with and without government control activities.

Economic Impacts of Exotic Pest Incidence: Supply-and-Demand Shifts

We modeled three scenarios. Each scenario considers different impacts that exotic pest policy might have on the supply of the listed California commodities and domestic and export demand. The supply function is shifted when the pest directly increases per-unit costs or lowers production of a commodity. Furthermore, producers would respond with measures to combat the infestations, which would limit yield losses, but also raise production costs. Overall, with a pest occurrence, we expect a shift back in supply and a lower quantity supplied.

Demand for a commodity is affected in some cases by potential negative impact on human health. More importantly, however, demand may be affected by embargos or restrictions on shipments of a commodity from California to regions or countries that are not yet infested with the pest. In order to account for such border measures and their impacts on demand, in the scenarios, we apply shifts in domestic demand for a commodity and shifts in international demand (that is, shifts in the demand for exports of a commodity).

In order to consider policy measures, the important information is the amount by which government policies concerning invasive species are likely to reduce the probability and severity of an outbreak. As noted above, each case specifies not the direct impact of the potential pest, but the degree to which the current policies reduce expected losses. Table 7 provides an overview of the scenarios that were modeled and the assumed shift in supply-and-demand shifts for each scenario. These scenarios each represent an alternative specification of the potential loss incurred if government pest control measures to reduce the probability and severity of an outbreak were abandoned.

Scenario 1 serves to identify the impacts on the higher production costs and reduced production that a producer faces as a result of an exotic pest outbreak. Scenario 2 assumes a 5% decrease in the supply along with a 5%decrease in the domestic demand and a 5% decrease in the international demand. Scenario 3 simulates a situation where the international demand response to an exotic pest outbreak is larger than the domestic demand response as a consequence of, for example, an embargo of a particular export market for a commodity.

Costs from Elimination of Protection from Exotic Pests

Our analysis solves a system of supply-and-demand equations for a new set of industry prices and quantities. The solution of the model proceeds as follows. Producers exhibit higher marginal costs of production because of the exotic pest infestation and reduced production. In all three scenarios, we shift the supply curve back by 5%. The scenarios then vary according to the effect of the exotic pest infestation on domestic and export demand as detailed above.

Effects on producers and consumers and overall benefits of the scenario with a supply shift only are detailed in Table 8. A reduction in supply of 5% raises the market price for each commodity, and the consumed quantity of the commodity decreases. The elasticities of supply-and-demand determine effects on producers and consumers. If the change in expected costs from removal of the pest policies affects California agriculture as a whole, total domestic losses (producers plus consumers) are about $1.26 billion. The quantity marketed decreases by more than is offset by the price increase, and California producers lose $664 million. Domestic U.S consumers lose $597 million. International consumers are only affected by the higher price resulting from the shift in the supply curve and experience small losses of $67 million. Total loss in global benefits is about $1.33 billion. Under this scenario of a supply shock only, California dairy producers lose $136 million, followed by the grape industry at $82 million and the greenhouse/nursery industry at $61 million.

The second scenario assumes a 5%shift back in the supply curve, together with a 5% downward shift in the domestic demand and a 5% downward shift in the export demand. Effects of this scenario are detailed in Table 9. As a result of the concurrent shifts in demand in this scenario, the new equilibrium price will be closer to the base price than in the previous scenario. In addition, the new equilibrium quantity is lower than in the previous scenario, because domestic and international demand for the commodity has decreased. Consequently, for California agriculture as a whole, the loss for producers almost doubles to $1.31 billion and domestic consumers experience losses of slightly more than $1.0 billion. International consumers lose $262 million, which brings global losses to $2.6 billion.

Under this scenario, the California dairy industry loses almost $203 million, followed by grapes at slightly over $122 million, and greenhouse/nursery at $106 million. International consumers lose more than their domestic counterparts for commodities that are mainly exported. Sixty percent of the almonds produced in California are exported and, therefore, international consumer benefits decrease by $36 million compared to $21 million domestically.

The third scenario assumes a larger fall in international demand in response to exotic pest infestations in California. International demand responses are likely to be larger than the domestic demand response through international embargos against California products, which are independent of the magnitude of pest outbreak. Obviously, losses to producers are higher than with a smaller international demand shifts, but domestic consumers lose less. Table 10 shows losses to California producers are $1.4 billion, losses to domestic consumers are $813 million, and total domestic losses are $2.25 billion. Global losses are $2.75 billion.

Losses to dairy producers with the larger international demand shift are $206 million, followed by grapes at slightly over $132 million, and the greenhouse/nursery sector at almost $107 million.

These results are on an annual basis and continue as long as the pest infestation continues. We note, however, that some demand embargo impacts may persist even after the outbreak is controlled, so that costs from a single pest occurrence may last several years. Therefore, these effects of pest occurrences are conservatively compared to annual costs of pest control supplied by public program.

Benefit-Cost Ratios

Increased expected economic losses from exotic pests experienced by consumers and producers that would follow from removal of government pest control programs can be compared to the actual costs of providing protection from invasive species. That comparison shows that domestic benefits outweigh government outlay costs by several multiples.

Budget costs listed in Table 2 are generally small compared to projected costs associated with the more probable and more severe outbreaks shown in Tables 8, 9 and 10. For example, if we consider only the domestic benefits associated with the 10 major commodities using the values in Table 8 (Scenario 1), which ignores any effects of an outbreak on demand, the cost of more likely and more severe pest and disease occurrences is $692 million. Total state and federal government costs of control, including the large one-time END eradication program, were $449.6 million in 2003, which is smaller than the projected costs to producers and consumers of allowing the pests and diseases to enter and remain in California, even under the limited scenario of Table 8.

Table 11 provides ratios that show the benefits of government programs from Tables 8, 9, and 10 (as the costs of the pest impacts that are avoided) divided by 449.6, which was the total government costs of those programs in 2003. The top two rows in Table 11 show the benefit-cost ratios for domestic benefits (i.e. to U.S. consumers and California producers) compared to the total costs of state and federal programs. The bottom two rows present ratios where only benefits to growers are used in the numerator. All the ratios exceed 1.0, except for the most restrictive case in which the full $449.6 million in government costs is compared to benefits that accrue only to California producers of the top 10 commodities. In this case, the benefits equal costs and the ratio is 1.0. Even if we restrict the benefits only to California producers and ignore gains to U.S. and foreign consumers, the benefit-cost ratios are between 1.5 and 3.2. When we recognize that U.S. consumers benefit as well, then the benefit cost ratios range from 2.8 to 5.3.

Conclusions

This research has gathered and summarized costs borne by the state and federal governments to deal with exotic pests and diseases that affect California agriculture. We also projected potential benefits of those programs under reasonable assumption about their effects on the supply of and demand for California commodities. Extensions of our research would include more detailed linkages between government programs and specific pests and the industries they affect. In addition, it would be useful to investigate a more detailed analysis of benefits by commodity and with more sensitivity testing across assumptions about market shocks from pest occurrences and elasticities of supply-and-demand. This would allow us to understand better the short-run as well as the long-run consequences of policy change. Finally, detailed analysis of more partial policy changes would be helpful to policy makers.

Overall, the results presented here strongly support the position that costs of increased probability and severity of pest occurrences exceed recent government outlays to protect against such occurrence.

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Table 1. Some important pests and major commodities affected.

Pierces Disease	Grapes and many other horticultural and ornamental crops
Classical Swine Fever	Swine
Exotic Newcastle Disease	Poultry, birds
Curly Top Virus	Beets, tomatoes, peppers, beans, potatoes, spinach, cucurbits, ornamentals
Citrus Tristeza	Citrus
BSE	Cattle, sheep, elk
Foot and Mouth Disease	Cattle, sheep, goats, swine
Nematodes	Grapes, lettuce, cotton, and others
Citrus Canker	Citrus
Red Imported Fire Ant	Livestock, crop, and human land use
Karnal Bunt	Wheat, durum wheat, and triticale
Ash Whitefly	Olives, Apple, Plum, Pear
Avocado Thrips	Avocado
Persea Mite	Avocado
Rice Blast Disease	Rice
Yellow Starthistle	Beef and other livestock grazing

Source: Sumner, 2003.

Table 2. Government agricultural exotic pest and disease control expenditures in California, 2003[a] .

Focus of program	Pest Control Activities	State	Federal	Total
			($ million)	
Plant	non PD & GWSS[b, c]	85.9	138.7	224.6
Plant	PD & GWSS only[c]	17.4	15.6	33.0
Plant	Subtotal	103.3	154.3	257.6
Animal	non END[d]	22.3	1.8	24.2
Animal	END only	2.7	165.0	167.8
Animal	Subtotal	25.1	166.9	192.0
Total		128.4	321.2	449.6

Source: Kreith, 2004.
[a] State fiscal year July 1, 2002 - June 30, 2003; Federal fiscal year October 1, 2002 - September 30, 2003
[b] PD is Pierce's disease; GWSS is glassy-winged sharpshooter.
[c] Does not include funds (research or non-research funds) to Universities for Pierce's disease or CDFA's $5 million annual assessment received from the wine grape industry for Pierce's disease research.
[d] END is exotic Newcastle disease.

Table 3. Agricultural animal-related invasive pest and disease control activities in California by state and federal governments, 2003 expenditures[a].

Animal-focused activities	Exclusion	Detection	Containment/ Suppression/ Eradication	Total all activities
			($million)	
State, non END[b]	*5.2*	*15.9*	*1.6*	*22.3*
State, including END	5.2	15.9	4.3	25.1
Federal, non END	*0.7*	*1.2*	*0.0*	*1.8*
Federal, including END eradication	0.7	4.6	161.6	166.9

Source: Kreith, 2004.
[a] State fiscal year July 1, 2002 - June 30, 2003; Federal fiscal year October 1, 2002 -September 30, 2003
[b] END is exotic Newcastle disease.

Table 4. Agricultural plant-related invasive pest and disease control activities in California by state and federal governments, 2003 expenditures[a].

Plant-focused activities	Exclusion	Detection	Eradication	Management/ Suppression	Total all activities
			($ million)		
State, non PD & GWSS[b]	*8.6*	*46.7*	*23.3*	*7.1*	*85.9*
State, including PD&GWSS	14.3	50.6	25.2	8.1	103.3
Federal, non PD & GWSS	*123.3*	*15.4*	*0.0*	*0.2*	*138.7*
Federal, including PD & GWSS	123.3	15.4	0.0	15.8	154.5

Source: Kreith, 2004.
[a] State fiscal year July 1, 2002 - June 30, 2003; Federal fiscal year October 1, 2002 - September 30, 2003
[b] PD is Pierce's disease; GWSS is glassy-winged sharpshooter.

Table 5. Revenue and export quantity shares[a] of California agriculture and top-10 commodities, 2003.

Commodity	Revenue	Export quantity
	($ million)	*(percent)*
Total CA agriculture	26,890	20
Dairy products	4,162	5
Greenhouse/nursery	3,271	1
Grapes	2,511	23
Lettuce	1,460	10
Almonds	1,180	63
Cattle/calves	1,380	7
Strawberries	959	12
Poultry/eggs	979	2
Citrus	805	30
Cotton	640	90
Sum of top-10	17,346	

Source: USDA, Economic Research Service: Farm Income Data

[a] Percentages are shares of the quantity that was marketed for export.

Table 6. Long-run elasticities of supply-and-demand facing California agriculture.

Commodity	Long-Run Elasticity		
	of supply	of domestic demand	of export demand
Total CA agriculture	1.0	-0.9	-2.0
Dairy products	1.0	-1.8	-4.0
Greenhouse/nursery	1.5	-1.9	-3.0
Grapes	1.0	-1.5	-2.5
Lettuce	1.5	-1.5	-1.5
Almonds	1.0	-1.0	-1.0
Cattle/calves	1.0	-3.6	-5.0
Strawberries	1.5	-1.0	-1.0
Poultry/eggs	2.0	-4.0	-4.0
Citrus	1.0	-1.8	-2.5
Cotton	2.0	-1.0	-4.0

Source: Huang (1993), Shumway and Lim (1993), Balagtas and Sumner (2003), Alston et al. (1995)

Table 7. Overview of scenarios reflecting expected effects of potential pest and disease infestations.

	Scenario 1	Scenario 2	Scenario 3
		(percent)	
Supply Shift	-5	-5	-5
Domestic Demand Shift	0	-5	-5
Export Demand Shift	0	-5	-10

Source: Author compilation

Table 8. Effects of elimination of government invasive-pest programs, which leads to more probable or more severe exotic pest or disease infestations and a reduction in supply by 5% (Scenario 1).

Commodity	California producer benefits	U.S. consumer benefits	Change in domestic benefits	International consumer benefits	Global benefits
	a	b	c=a+b	d	c+d
			($ million)		
Total CA agriculture	-664.1	-596.8	-1,260.9	-67.3	-1,328.2
Dairy products	-136.4	-66.5	-202.9	-1.7	-204.6
Greenhouse/nursery	-61.4	-45.8	-107.2	-0.2	-107.5
Grapes	-82.3	-36.3	-118.7	-4.8	-123.5
Lettuce	-24.0	-22.8	-46.8	-1.2	-48.1
Almonds	-29.1	-19.8	-49.0	-9.3	-58.3
Cattle/calves	-54.1	-13.0	-67.1	-0.5	-67.6
Strawberries	-12.7	-17.8	-30.5	-1.2	-31.7
Poultry/eggs	-16.0	-7.9	-24.0	-0.1	-24.1
Citrus	-26.4	-11.2	-37.6	-2.0	-39.6
Cotton	-9.5	-3.4	-12.9	-2.9	-15.8
Sum of top-10	-451.9	-240.4	-692.3	-28.2	-720.5

Source: Author simulations using model described in text

Table 9. Effects of elimination of government invasive-pest programs, which leads to more probable or more severe exotic pest or disease infestations and a reduction in supply, domestic demand, and international demand by 5%(Scenario 2).

Commodity	California producer benefits	U.S. consumer benefits	Change in domestic benefits	International consumer benefits	Global benefits
	a	b	c=a+b	d	c+d
			($ million)		
Total CA agriculture	-1,311.4	-1,049.1	-2,360.5	-262.3	-2,622.8
Dairy products	-202.9	-96.4	-299.3	-5.1	-304.4
Greenhouse/nursery	-106.3	-78.9	-185.2	-0.8	-186.0
Grapes	-122.4	-47.1	-169.6	-14.1	-183.6
Lettuce	-47.4	-42.7	-90.1	-4.7	-94.9
Almonds	-57.5	-21.3	-78.8	-36.3	-115.1
Cattle/calves	-67.3	-15.6	-82.9	-1.2	-84.1
Strawberries	-31.2	-41.1	-72.3	-5.6	-77.9
Poultry/eggs	-23.9	-11.7	-35.5	-0.2	-35.8
Citrus	-39.3	-13.7	-53.0	-5.9	-58.9
Cotton	-15.6	-1.0	-16.6	-9.4	-26.0
Sum of top-10	-713.7	-369.7	-1,083.4	-83.2	-1,166.6

Source: Author simulation using model described in text

Table 10. Effects of elimination of government invasive-pest programs, which leads to more probable or more severe exotic pest or disease infestations and a reduction in supply and domestic demand by 5% and international demand by 10% (Scenario 3).

Commodity	California producer benefits	U.S. consumer benefits	Change in domestic benefits	International consumer benefits	Global benefits
	a	b	c=a+b	d	c+d
			($ million)		
Total CA agriculture	-1,438.8	-812.7	-2,251.5	-499.0	-2,750.5
Dairy products	-206.2	-90.8	-297.0	-9.8	-306.8
Greenhouse/nursery	-106.7	-78.1	-184.9	-1.6	-186.4
Grapes	-131.5	-32.5	-164.0	-26.4	-190.5
Lettuce	-49.8	-38.3	-88.1	-9.1	-97.2
Almonds	-75.1	7.7	-67.4	-65.4	-132.7
Cattle/calves	-76.4	-14.2	-90.6	-2.3	-92.9
Strawberries	-33.4	-36.5	-69.8	-10.8	-80.7
Poultry/eggs	-24.0	-11.4	-35.4	-0.5	-35.9
Citrus	-43.1	-7.8	-50.8	-10.9	-61.7
Cotton	-21.0	6.4	-14.7	-15.9	-30.6
Sum of top-10	-767.1	-295.6	-1,062.7	-152.7	-1,215.4

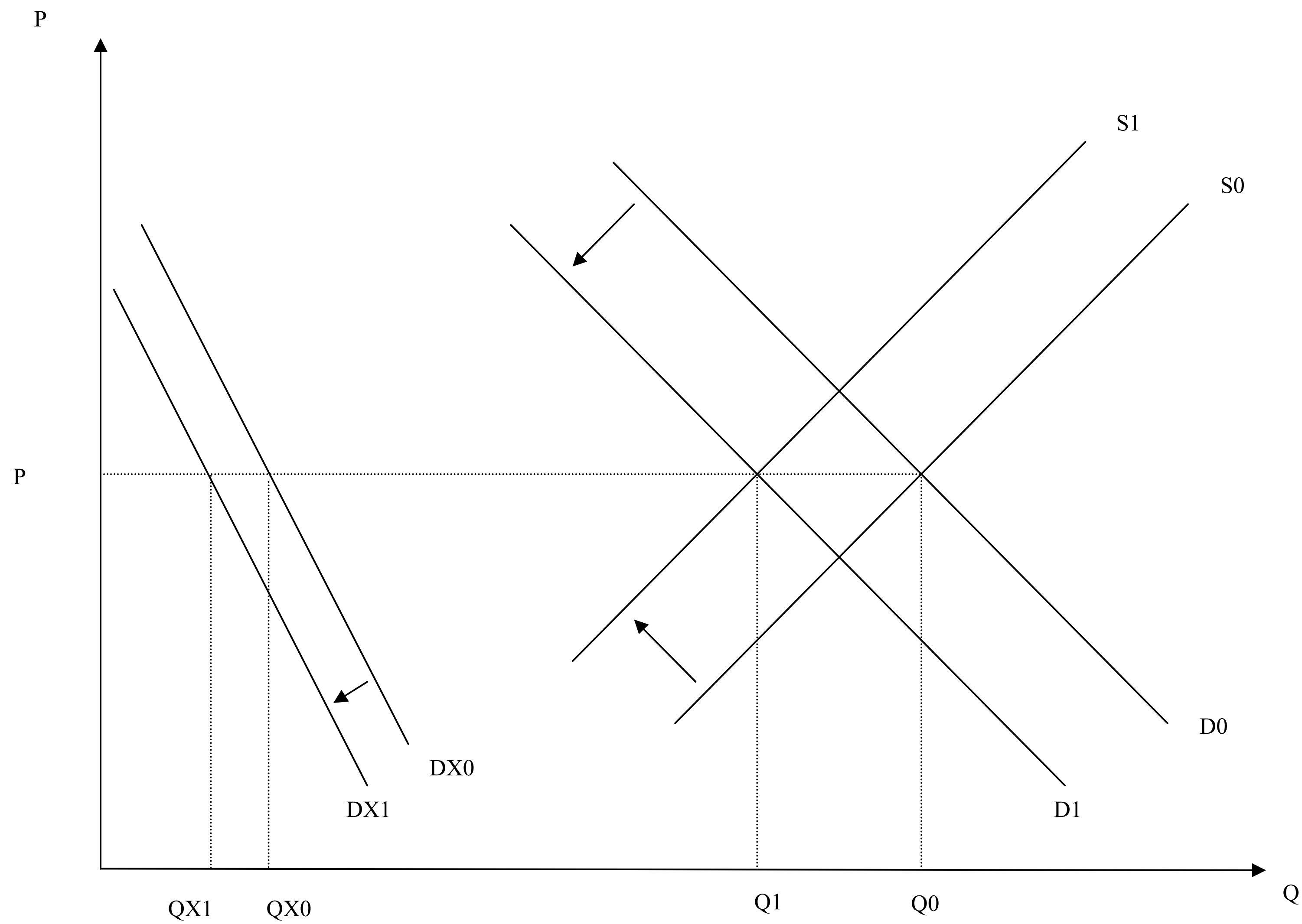
Source: Author simulation using model described in text

Table 11. Benefit-cost ratios for California and federal outlays under alternative supply-and-demand impacts.

Scenarios:	Scenario 1[a] (5/0/0)	Scenario 2[b] (5/5/5)	Scenario 3[c] (5/5/10)
		(benefit/cost ratios)	
CA producers plus U.S. consumers			
Top-10 CA crops	1.5	2.4	2.4
All CA crops	2.8	5.3	5.0
Producers only			
Top-10 crops	1.0	1.6	1.7
All CA crops	1.5	3.3	3.2

Source: Author calculation
[a] Scenario 1 assumes 5% decrease in supply.
[b] Scenario 2 assumes 5% decrease in supply, domestic demand, and export demand.
[c] Scenario 3 assumes 5% decrease in supply and domestic demand, and 10% decrease in export demand.

Figure 1. Illustration of simulated supply-and-demand curve shifts caused by exotic pests not controlled by government policies.



THE EFFECT OF A RURAL COOPERATIVE ASSOCIATION ON THE RURAL ENVIRONMENT

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Abstract
Environmental degradation, especially soil erosion, has been a serious problem in Iran for decades. One of the fundamental trends in Iranian government after the Islamic revolution has been implementation of consistent strategies for overcoming problems of rural areas. Among environmental policies for dealing with rural problems and striving for sustainable production is the concept of the rural cooperative. Public investment for rural management is closely connected to environmental creation. A program launched in Darab Township, in cooperation between one government office of the Fars province and the people of that area, is establishing a cooperative association. This program is based on the concept of inhabitants' participation. Development of the program was designed for environmental creation and also to minimize environmental damage. This program is a means to achieve multiple objectives such as improving agricultural productivity, making more attractive landscapes, and increasing water storage. Most of the act applied in the village of Navaigan can be considered and adapted for other rural areas. Two hundred residents of Navaigan were asked to answer a survey questionnaire, with 197 questionnaire surveys completed. Questions asked residents to evaluate various aspects of the rural cooperative situation. In this study, the questionnaire technique is emphasized, and statistical analysis of the questionnaire is presented by applying the EXCEL program.

Key words: rural cooperative association, rural environment protection, questionnaire

Introduction

In most developing countries, “small farmers” constitute a significant proportion of the total farming population. Nowadays, most of their villages are in various stages of transition from traditional to modern state. In the course of their modernization, rural areas have experienced the deteriorating condition of the rural environment, and it has become more and more complicated and diversified. The functions of living environment are also strongly influenced by inhabitants' ideas or their social agreement. The inhabitants’ requirements for planning have become complicated, and also it is difficult to find a consensus among them.

Many rural environmental impacts have a direct bearing on production values. Pollution may directly damage the production of crops, fish, potable water, or irrigation water. Environmental creation is a part of the social responsibility to overcome environmental problems.

"Rural environmental creation" is a commonly used term in rural sustainable development literature, as well as in policymaking and implementation by both governmental and non-governmental bodies. It can be defined as an interventionist process leading to sustainable improvement in the living standard and welfare of the people living in rural areas.

The basic problem in the management of environmental resources is the inhabitants' incentives. Environmental resources are often such that it is not in the best interest of individuals to act in a way that is a best for the society at large. The basic objective of environmental policy is to create an economic environment in which the incentives are correct, that is, to create an organization which will be in the best interest of individuals, households, local communities, farmers, etc.

Cooperative association is a voluntary organization that can be open to rural inhabitants. Acceptance of the membership should exclude gender, social, racial, and political discrimination. Cooperatives exist in a variety of sectors, including agriculture, irrigation, food processing, handicraft, carpet weaving, metal work, printing, health, educational trusts, water supply, recreation, consumer cooperatives, etc.

Some cooperative organizations' efforts have been directly involved in environmental problems. They are for the purpose of enabling members to meet their basic needs. Their social responsibilities are to create communities where people can enjoy their villages by working together.

The history of Iran shows that the first cooperative law in Iran was enacted in 1925, which was amended in 1948, in 1952, and then in June 1971. After the Islamic revolution in Iran, the earlier cooperative society law of June 1971 was replaced by the "Law of the Cooperative Sector" on September 4, 1991. The new law has 71 articles with 12 chapters, against 149 articles with 25 chapters in the old one.

Iran's government has played an important facilitating role in promoting this reform process. It has assisted local governments to establish rural cooperatives in a number of villages, including Navaigan. One program launched in Darab Township is a cooperation between one government office of the Fars province and the people of that area. This program is based on the concept of inhabitants' participation. This project is a means to achieve environmental creation, such as improving agricultural productivity, making more attractive landscapes, and increasing water storages. Accordingly, the aim of this study was to apply a watershed cooperative association for rural environmental creation based on a model reference adaptive theory.

To accomplish this purpose, this paper is organized as follows: after the introductory part, the situation of the investigated village is introduced in Section II, followed by the explanation of the methodology in Section III. The result of the study is shown in Section IV, and finally, the conclusions are presented in Section V.

The Investigated Village

The Navaigan area is located in the Fars province in the south of Iran. Figure 1 shows the location of Navaigan area, which belongs to Darab Township. The Navaigan area is 20,000 hectares and its population is 2,561 people, among which the agricultural occupation involves 80% of the total families. The average altitude is 1560 meters above sea, and the climate is temperate.

The Navaigan area is one of the Iranian regions with less soil and water. The biological environment is worsening gradually in this area, and the productivity of land is decreasing. Due to these facts, the government of the Fars province gave backing to the area. For the purpose of sustainable development of the area, environmental creation has to be regarded as a process. The government knows that there is no intervention from outside for any of these purposes. For the process of becoming self-sustaining needed to be implemented. Rural people should take part in identifying and choosing both the process of change and its final result, in addition to managing this process. A significant role assigned to the people’s participation in the change is to construct an organization, like a watershed cooperative, for this purpose. Biological environment and production conditions could be improved if good strategy would be implemented.

People of the village and the Fars government cooperated to form a watershed cooperative association in 1996. The main target of the government was to make efforts to achieve sustainable development in the area. Cooperative works for the sustainable development of Navaigan area through policies were approved by the inhabitants.

The attempt to sensitize cooperatives in the village encouraged Navigan inhabitants to introduce environment-friendly programs, including use of organic fertilizers. Reforestation has become a main work of environmental conservation activities in the cooperative. It plays a leading role in environmental conservation activities, being in harmony with rural sustainable development.

Main environmental factors, such as bio-climatic factors of environment, soil and water quality, and pollution of soil, surface and underground waters, were the main targets of this new cooperative association.

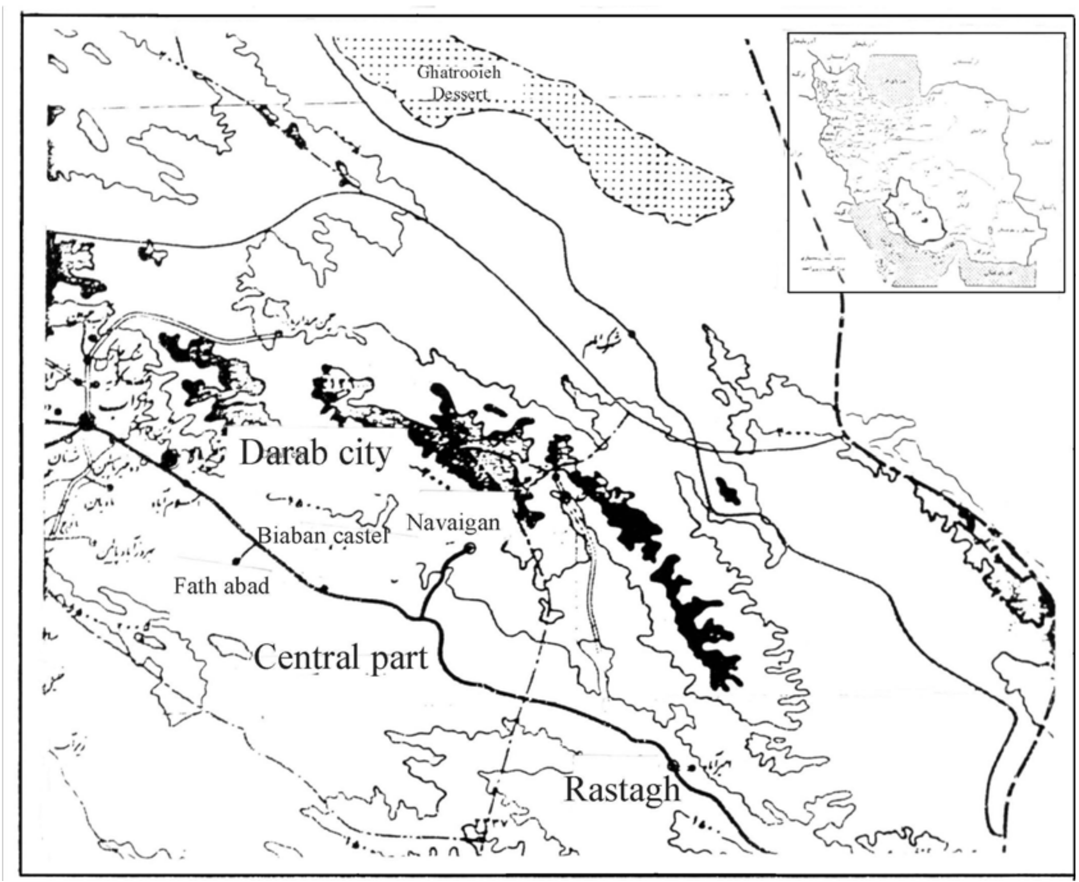

Figure 1. The location of Navaigan area.

There were 396 members in this association at the beginning, but after less than six years it has grown to 517 members. After establishing the cooperative association in the Navaigan in 1996, the board of directors did many good activities in the area, including the following:

1. official registration in governmental office
2. choosing their own office
3. receiving more than 2,000 million Rails, a low interest loan from the governmental bank to control environmental problems
4. preparing petroleum and gas for the area to stop using trees for fire woods
5. controlling hunting of wild animals
6. establishing suitable small-scale industries for the area
7. giving scholarships to two members to study watershed management the Besat education center
8. giving more than 130 tons of barely to feed the domestics animals to decrease using the low pasture areas
9. constructing health center in the village
10. starting a fish culture project in the area

Finally, the soil and water conservation techniques were implemented in the area. The above management regulations have a good extensive work in the area.

Study Methodology

Because, the problems of most rural areas are the same, applying a successful policy in the development of other rural areas is very useful. Navaigan is a rural area that has experienced development of Watershed Cooperative Association for Environmental Creation. It is necessary to review the watershed cooperative association started in 1996.

When thinking of the adaptation policies by the model, it is important to note that actual social environment is to become the effective circulation by the social environment value criteria, based on the human recognition and expression mechanism, and sense.

Data reported in this study were collected using a questionnaire survey (see Appendix for the complete questions). Design of the survey questions and methods for conducting this research closely follow Dillman's Total Design Method (Dillman 1999). This methodology makes a design of a survey relatively easy to complete. The population of interest in this study included all adults (18 years of age or older) living in the Navaigan village. The sample was obtained through a random survey sampling. The questionnaire carried out in this study consisted of 15 questions were presented in either a short answer or multiple-choice format.

Two hundred residents of the entire population of the Navaigan village were asked to answer the survey questionnaire. One hundred and ninety-seven questionnaire surveys were completed. The surveys included questions, asking residents to evaluate various aspects on the watershed cooperative situation. The questionnaire survey was carried out between April 20-28, 2006. The questionnaire survey employed a direct interviewing method.

In order to analyze the questionnaire, it was assessed to see how the watershed cooperative association had generated publicity and increased local awareness. This was done by asking respondents to judge how likely it is that the watershed cooperative association has been successful. It refers to the degree to which an individual feels that the watershed cooperative association is working for environmental creation. The statistical analysis of the questionnaire was carried out by applying the EXCEL program.

Selected Study Results

This section is devoted to the results of the questionnaire. The tables presented here explain characteristics of respondents and the effect of the cooperative association on the area.

A. Characteristics of Respondents

More than 64% of the respondents were members, and 35.9% were nonmembers (Table 1.).

The respondents were disproportionately male, but no significant difference existed between the mean of members and nonmembers (male 67.8%; female 32.2%, Table 2.). This bias was primarily due to the fact that some women in the area were ashamed to accept the interview.

The mean age of respondents was approximately 38 years (Table 3). The mean age for members was slightly younger than nonmembers, with an average of 0.9 years, but no significant difference existed between the mean ages of members and nonmembers.

More than 85% of respondents were married and 13.6% were single, but no significant difference existed between the mean ages of members and nonmembers (Table 4).

More than 40% of respondents of both members and nonmembers were "Not educated" (Table 5). No significant differences existed between members and nonmembers respondents with regards to the educational level.

Table 1. Percentage of respondents that are members.

Member	Respondents	
	n	%
Yes	126	64
No	71	36
Total	197	100

Table 2. Gender of respondents.

Gender	Respondents			
	Members		Nonmembers	
	n	%	n	%
Female	39	31	26	36.6
Male	87	69	45	63.4
Total	126	100	71	100

Significant at 0.66
Not Significant

Table 3. Age of respondents.

Age	Respondents			
	Members		Nonmembers	
	n	%	n	%
<30	48	38.1	26	36.6
<40	31	24.6	14	19.7
<50	21	16.7	16	22.5
<60	11	8.7	5	7.1
>60	15	11.9	10	14.1
Total	126	100	71	100

Chi square = 1.6
Not Significant

Table 4. Marital status of respondents.

Status	Respondents			
	Members		Nonmembers	
	n	%	n	%
Single	14	11.1	13	18.3
Maride	112	88.9	58	81.7
Total	126	100	71	100

Chi square = 1.9
Not Significant

Table 5. Education level attained by respondent.

Level	Respondents			
	Members		Nonmembers	
	n	%	n	%
No Educ	53	42.1	27	38.1
Element	40	31.7	20	28.2
Second	15	11.9	14	19.7
High.S	11	8.7	4	5.6
Univ.	7	5.6	4	5.6
No Answer	0	0	2	2.8
Total	126	100	71	100

Chi square = 6.3
Not Significant

B. Comparison of Members and Nonmembers

Statistics and information on results focused on the beliefs of respondents, as well as the differences between the members and nonmembers.

Significantly more respondents of members (73.8%) participated in the cooperative association meetings than did nonmembers (32.4%) (chi-square = 24.3, sig. at .001 in Table 6.

More than 80% of respondents believe that the village environmental creation activities have improved after establishing the cooperative association. Significantly more respondents of members (88.1%) wrote yes than did nonmembers (70.4.4%). (Chi-square = 9.49, sig. at .002 in Table 7.)

The great majority of respondents believe that the cooperative association is successful in different activities. Tables 8, 9, and 10 show the results.

No significant difference exists between members and nonmembers with regard to their expectation of the cooperative association work (Table 11).

Significant differences exist between members and nonmembers with regard to their viewpoint on their village (Chi-square = 26, sig. at .0001 in Table 12).

Tables 13 to 16 show some results of the survey by comparing members and nonmembers. The information collected concerning opinions about the watershed cooperative association in Navaigan is influenced by the degree to which individuals are familiar with watershed cooperative association activities. Question 15 assessed respondents' familiarity with the watershed cooperative association. The results in Table 17 indicate that respondents of members were significantly more familiar than nonmembers (chi square = 4.36, sig. at .03).

A very small number of respondents (5%) were not satisfied with the watershed cooperative association, but significant differences existed between members and nonmember respondents with regards to satisfaction (Chi-square = 14.8, sig. at .0002 in Table 18).

According to the comparison between members' and nonmembers' beliefs, it is important to reduce the difference of social environment between their beliefs. The parallel model can reduce the differences.

Table 6. Participation rate of respondents.

Participate	Respondents			
	Members		Nonmembers	
	n	%	n	%
Yes	93	73.8	23	32.4
No	32	25.4	47	66.2
No Answer	1	0.8	1	1.4
Total	126	100	71	100

Chi square = 24.3
Significant at 0.001

Table 7. Percentage of respondents who think the activity of the cooperative association has augmented.

Improve	Respondents			
	Members		Nonmembers	
	n	%	n	%
Yes	111	88.1	50	70.4
No	10	7.9	10	14.1
No Answer	5	4	11	15.5
Total	126	100	71	100

Chi square = 9.49
Significant at 0.002

Table 8. Percentage of respondents who think the cooperative association is successful in giving loan.

Succesful in Giving Loan	Respondents			
	Members		Nonmembers	
	n	%	n	%
Yes	116	92.8	52	76.5
No	9	7.2	16	23.5
No Answer	1	0.8	3	4.4
Total	125	100	68	100

Chi square = 12.8
Significant at 0.0003

Table 9.Percentage of respondents who think the cooperative association is successful in recreational activity.

Succesful in Recreati Activity	Respondents			
	Members		Nonmembers	
	n	%	n	%
Yes	112	91.8	55	80.9
No	10	8.2	13	19.1
No Answer	4	3.3	3	4.4
Total	122	100	68	100

Chi square = 4.59
Significant at 0.032

Table 10. Percentage of respondents who think the cooperative association is successful in development activity.

Succesful in Devel. Activity	Respondents			
	Members		Nonmembers	
	n	%	n	%
Yes	101	82.1	53	79.1
No	22	17.9	14	20.9
No Answer	3	2.4	4	6
Total	123	100	67	100

Chi square = 0.47
Not Significant

Table 11.Compare the work done by the Cooperative Association relative to respondents' expectations.

Expect	Respondents			
	Members		Nonmembers	
	n	%	n	%
Better Thar	110	87.3	50	70.5
About As	3	2.4	5	7
Better Som	3	2.4	5	7
Not as	8	6.3	10	14.1
No Answer	2	1.6	1	1.4
Total	126	100	71	100

Chi square = 6
Not Significant

Table 12. Respondents' evaluation of the situation in their village.

Village Rate	Respondents			
	Members		Nonmembers	
	n	%	n	%
Excelent	114	90.4	45	63.4
Good	7	5.6	6	8.5
Average	3	2.4	15	21.1
Below	2	1.6	3	4.2
Poor	0	0	2	2.8
Total	126	100	71	100

Chi square = 26
Significant at 0.0001

Table 13. Percentage of respondents who think their involvement in environmental creation has changed.

Involvement	Respondents			
	Members		Nonmembers	
	n	%	n	%
More Inv.	115	91.2	35	49.3
Same	4	3.2	25	35.2
Less Inv.	6	4.8	6	0.08
No Answer	1	0.8	5	0.07
Total	126	100	71	84.65

Chi square = 26
Significant at 0.0001

Table 14. Percentage of respondents' who think the environment of the village has changed.

Change	Respondents			
	Members		Nonmembers	
	n	%	n	%
Imorove	107	84.9	51	71.9
No Change	17	13.5	17	23.9
Worse	1	0.8	1	1.4
No Answer	1	0.8	2	2.8
Total	126	100	71	100

Chi square = 2.66
Not Significant

Table 15. Percentage of respondents who would like to get more involved in village activities.

Like to Involve in Vil. Activ.	Respondents			
	Members		Nonmembers	
	n	%	n	%
More	112	88.9	54	76.1
Same	5	3.9	10	14.1
Less Inv.	7	5.6	3	4.2
No Answer	2	1.6	4	5.6
Total	126	100	71	100

Chi square = 9.5
Significant at 0.02

Table 16. Percentage of respondents who believe in importance of the watershed cooperative association.

Important	Respondents			
	Members		Nonmembers	
	n	%	n	%
Very Imp.	115	91.3	59	83.1
Fairly Imp.	9	7.1	6	8.5
Not Impo.	2	1.6	5	7
No Answer	0	0	1	1.4
Total	126	100	71	100

Chi square = 6
Not Significant

Table 17. Number of activities of the cooperative association perceived to be significant.

Activity	Respondents			
	Members		Nonmembers	
	n	%	n	%
One Act.	4	3.2	5	7
Two Act.	22	17.5	15	21.1
Three Act.	88	69.8	32	45.1
No Answer	12	9.5	19	26.8
Total	126	100	71	100

Chi square = 4.36
Significant at 0.03

Table 18. Percentage of respondents who are satisfied with the cooperative association.

	Respondents			
	Members		Nonmembers	
	n	%	n	%
Satisfy	113	89.7	48	67.6
No Idea	7	5.6	18	25.4
Unsatisfied	6	4.7	4	5.6
No Answer	0	0	1	1.4
Total	126	100	71	100

Chi square = 14.8
Significant at 0.0002

Concluding Remarks

This study examined the watershed cooperative association for rural environmental creation based on the model reference adaptive theory. Inhabitants of the Navaigan village responded to a questionnaire and were asked to evaluate the watershed cooperative association. Results indicated that the cooperative had a positive impact on residents' lives in a wide variety of areas. After establishing the watershed cooperative association in less than six years, the residents were very satisfied with it. This study suggests that the watershed cooperatives are a promising alternative for rural environment development.

Survey results indicate that despite some notable differences between member and nonmember respondents, several conclusions can be drawn from the study on rural environmental creation.

Local inhabitants have a strong interest in the watershed cooperative association because it enhances people's confidence, creates local amenities, and has developed the area.

Recognizing the importance not only of the government but also private organizations in promoting environmental creation activities, this study analyzes the current activities of the watershed cooperative, which is a private organization in Navaigan. It shows that important roles can be played by such anorganization in the establishment and operation of environmental protection tools and facilities, and environmental protection activities, including a forest station and recycling of resources.

Local inhabitants have a strong interest in the watershed cooperative association, because the cooperative has been able to provide a variety of social services in the village for their members and nonmembers.

Results of the survey can lead to establishing watershed cooperative association in other rural areas in the future. The government, in order to improve the rural environment, can thus effectively use co-operatives as institutions of the people.

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Appendix

Questionnaire of Navaigan Region

Q 1. Characteristics of replier

1.1 Gender: A. Male ( ) B: Female ( )

1.3 Age (Years) ( )

1.3 Martial Status: A: Single ( ) B: Married ( )

1.4 Educational Status

A: Not Educated ( ) B: Elementary School ( )

C: Secondary School ( ) D: High School ( ) E: University ( )

Q 2. Are you member of the cooperative association?

A: Yes B: No

Q 3. Do you participate in the cooperative association meetings?

A: Yes B: No

Q 4. Has the activity of the cooperative association improved rural environmental creation?

A: Yes B: No

Q 5. Is the cooperative association successful in giving loan?

A: Yes B: No

Q 6. Is the cooperative association successful in recreational activity?

A: Yes B: No

Q 7. Is the cooperative association successful in development activity?

A: Yes B: No

Q 8. Would you say that the watershed cooperative association had worked on environmental creation as you expected, better than you expected, or not as well?

1- Better than expected 2- About as expected

3- Better in some ways, not in others 4- Not as well as expected

Q9. I'd like to ask you how you feel about this village as a place to live. From your own personal point of view, would you rate this village as a place to live as excellent, good, average, below average, or poor?

1-Excellent 2-Good 3- Average 4- Below Average 5- Poor

Q10. Think of your involvement in environmental creation in the past foud years. Would you say, you are more involved now, or less involved now than you were four years ago?

1- More involved now 2- Same as before 3- Less involved now

Q 11. Has the environment of the village changed since the establishment of the cooperative association?

A: Improved B: No Change C: Worsened

Q 12. Some people would like to be more involved in village activities than they are, while others would like to be less involved. How about you? Would like to be more involved, less involved, or about as involved as you are now?

A- More involved B- Same as now C- Less involved

Q13. How important is the watershed cooperative association in your village to you?

A- Very important B- Fairly important C- Not important at all

Q 14. What are three important activities of the Cooperative Association?

1: 2: 3:

Q 15. Are you satisfied with the cooperative association?

A: Satisfied B: No idea C: Unsatisfied

GENETIC ENHANCEMENT OF AGRO-BIODIVERSITY, AGROSUSTAINABILITY, AND ENVIRONMENTAL QUALITY

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Abstract
Biological resources are the foundation for agricultural productivity and for many aspects of conservation of land and water resources. This presentation will emphasize the importance of conservation of biological resources in general and of genetic resources for manipulation of managed agroecosystems. For example, host plant resistance in crop plants provides immediate protection from diseases and pests and eliminates need for pesticide applications, and eliminates pesticide residues on consumable plant parts. This is but one example of how genetic resources are a vital component of sustainability in agriculture that enhances biodiversity and environmental quality. We will illustrate with simple Venn diagrams how these three components interact and how an agroecosystem can be managed to benefit biodiversity conservation, to sustain agricultural productivity and profitability, and to provide protection to consumers and the environment.

Key words: biodiversity, agroecosystems, genetic resources

PM-10 EMISSION REDUCTIONS: HOW AGRICULTURE IS ADAPTING "A SUCCESS STORY"

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Abstract
The San Joaquin Valley, home to three of the highest agricultural producing counties in the nation, is classified as being in serious non-attainment for PM-10 standards established under the Clean Air Act. Agriculture is a major land use within the eight counties of the valley. The state implementation plan (SIP) completed by the San Joaquin Valley Air Pollution Control District mandated the PM-10 emissions emanating from agricultural sources must be reduced by 34 tons/day. Agriculture responded to this regulatory mandate by supporting the establishment of an air quality coalition. This coalition, Agriculture Improving Resources (AIR), is made up of agricultural commodity representatives, government agencies, and air quality regulators - 21 entities in all. AIR organized grower-group, commodity-specific meetings to assist regulators in determining air-enhancing conservation practices. Out of these meetings, more than 80 plus practices were identified that if adopted on farms, dairies, feedlots, and poultry houses, would result in reduced PM-10 emissions from agriculture sources. These 80 practices were organized into an Air Quality - Conservation Management Plan (CMP) document. With the local air district mandating a 34 ton/day PM-10 reduction, the CMP process became an integral piece for documenting emission reductions. Individual growers selected one or more practices in each of five categories (land preparation/cultivation, harvest activities, unpaved roads, unpaved equipment yards, and other cultural practice) that when applied on their property would result in reduced PM-10 emissions. Results: Through the united effort of the AIR partnership, more than 35 grower educational/informational meetings were held within the eight-county areas. More than 4,000 growers participated in these meetings. More than 6,000 CMP plans were developed and sent to the air district. The CMP plans encompassed more than 3.2 million acres of farmland and more than 30,000 miles of unpaved roads. The PM-10 emissions reductions achieved are quantifiable and enforceable through the approved CMP plans and inspections. The AIR collaborative effort responsible for the CMP program received U.S. EPA Region IX's 2005 Environment Award for Outstanding Achievement. PM-10 emission reductions from agricultural sources were documented at more than 35 tons/day.

Key words: air quality, PM-10, CMP, agriculture, emissions, conservation farming systems

ASSESSING THE POTENTIAL FOR GREENHOUSE GAS MITIGATION IN CALIFORNIAN SOILS

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Abstract
The effects of increased greenhouse gas (GHG) concentrations in the atmosphere on climate change are beyond dispute. The role of agricultural management on atmospheric GHG gas concentrations is significant, not only because agriculture makes a significant contribution to increasing the global budget, but also because there is the possibility of adjusting agricultural management to sequester carbon in the soil and reduce GHG emissions. The science of these effects has matured to a point where global budgets of GHG fluxes may be estimated, and we are able to pinpoint the effect of different crop production scenarios to mitigate GHG fluxes. Therefore, a detailed analysis of the GHG emissions and economic costs associated with alternative agricultural management systems may be provided to policy makers, in an effort to compensate farmers for their investments. This requires a detailed estimation of the total GHG fluxes for baseline and alternative management scenarios across a wide range of crops, soils, and climates. Since it is impossible to continuously monitor GHG fluxes across all these gradients and their interactions, ecosystem process models are used to simulate gas exchange for different cropping systems, soils and climates, and site managements. We used DayCent, a daily version of the CENTURY model, to simulate GHG fluxes over Yolo county in California. We used the most detailed data available. Soil information was extracted from soil survey geographic database (SSURGO); information on land use was acquired from department of water resources (DWR), and climate information from California irrigation management information system (CIMIS). A framework was developed to couple the process model DayCent to a GIS database, which allowed us to easily carry out a large number of simulations over different gradients of soils, climates, crops, and managements and interactions of these. To validate this model, we compiled data from four long-term agricultural experiments in California and attempted to model these cropping systems using the coupled GIS-DayCent framework. Management practices that were investigated included standard tillage, conservation tillage, organic farming methods, and the use of winter cover crops. A preliminary analysis shows that reducing tillage intensity decreases GHG emissions to some extent. This was mainly due to a reduction of the emission from fuel carbon, and not a decrease in soil GHG emissions, since the soil carbon (C) sequestration was offset by increases in N2O emissions. The most important management option that led to a net mitigation of greenhouse gases was the inclusion of a winter cover crop in conservation tillage systems. Organic amendments also increased soil C sequestration, but did not lead to a net greenhouse gas mitigation. In a next step, we extrapolated these results and ran the model at a county level. The net potential of different management options for each soil and crop combination was determined.

Key words: greenhouse gases, global change, alternative agricultural management, conservation farming systems

Introduction

The effects of increased greenhouse gas (GHG) concentrations in the atmosphere on climate change are beyond dispute. The role of agriculture on atmospheric GHG gas concentrations is significant. This is in part because, historically, agriculture has been a major source of CO_2 and N_2O to the atmosphere (Cole et al., 1993). Currently, it is estimated that 8 % of the total greenhouse gas emission is emitted by agriculture and forestry in California (CEC, 2005). This percentage was larger in pre-industrial times. However, changes in agricultural practices aimed at soil conservation and the increase in crop productivity due to the implementation of new technologies are believed to have stabilized or even increased soil C stocks during the past few decades (Cole et al., 1996; Paustian et al., 1997; Buyanovsky and Wagner, 1998). By comparing archived soil samples to contemporary samples, DeClerck and Singer (2003) concluded that soil carbon even increased over the last 60 years in California. However, this increase in crop productivity and the intensification of agriculture also increased N_2O emissions, mainly derived from the increased use of inorganic fertilizer. In California, for example, it is estimated that N_2O is responsible for 50 % of the total radiative forcing by GHGs emitted by agriculture, while CH_4 is responsible for 37.5 % and CO_2 only for 12.5 % (CEC, 2005).

Agricultural soils management has been advocated as a viable option in the portfolio of technologies needed to limit the increase in greenhouse gas concentrations over the next 50 years (Pacala and Socolow, 2004). Examples of management options that have been proposed comprise the reduction of soil disturbance by tillage, planting a winter cover crop, the introduction of organic practices, planting deep rooting crops, and increasing the number of hay crops in rotations. However, before policy makers can establish guidelines and incentives for farmers to implement these practices, a detailed analysis of the GHG emissions and economic costs associated with alternative agricultural management systems is pertinent. Such a detailed analysis requires an accurate estimation of the total GHG fluxes, for baseline and alternative management scenarios across a wide range of crops, soils, and climates.

It is impossible to continuously monitor the GHG fluxes across all gradients of crop rotations, soil types, microclimates, and their interactions. Therefore, ecosystem process models have been used to simulate gas exchange for different cropping systems, soils and climates, and site managements. The science of ecosystem nutrient dynamics has matured to a point where we can determine the effect of different crop production scenarios on the mitigation of GHG fluxes and estimate regional and even global budgets of GHG fluxes.

The aim of this study was to model the short-term (10-yr) change in crop yield and GHG emissions when conventional agricultural practices are changed to alternative practices at a regional scale (county). The crops are modeled in their typical rotations. The alternative practices considered included reduced tillage, winter cover cropping, and organic practices.

Materials and Methods

Model description

We used DayCent, a daily version of the CENTURY model, to simulate GHG fluxes in Yolo County, California. The DAYCENT model is the daily time-step version of the CENTURY (Parton et al., 1987, 1994; Metherell et al., 1995) ecosystem model. DAYCENT was developed to simulate ecosystem C and nutrient dynamics as well as trace gas fluxes. It includes submodels for nitrification and denitrification (Parton et al., 1996; Del Grosso et al., 2000), CH4 oxidation (Del Grosso et al., 2000), and a detailed soil water/temperature submodel (Parton et al., 1998). It is a fully resolved ecosystem model simulating the major processes that affect soil organic matter (SOM), such as plant production, water flow, nutrient cycling, and decomposition. The model simulates soil organic C and N stocks, which are represented by two plant litter pools and three SOM pools (termed active, slow, and passive). The active, slow, and passive pools are explicitly defined by their turnover. The active pool is assigned a turnover time of one to five years and contains more labile components, such as the microbial biomass. The slow pool of SOM is assigned a turnover time of 20 to 40 years. It represents plant and microbial products stabilized in the soil that are more resistant to decomposition (e.g., lignin-like components). Passive SOM is assigned the longest turnover time of 200 to 1500 years and includes the physically "protected" or chemically recalcitrant forms of organic matter. Material flows between pools are driven by microbial activity. The crop sub-model simulates crop growth, dry matter production, and yields to estimate the amount and quality of residue (i.e. C input) returned to the soil, as well as plant influence on soil water, nutrients, and other factors affecting SOM turnover and trace gas emissions. The model allows for functional characteristics of the vegetation to be parameterized that have an influence on productivity. This includes phenology, C to N ratios, C allocation between roots and shoots, and growth responses to temperature. Soil organic matter decomposition is per-pool dependent on moisture, temperature, soil texture, and the decay constant for each SOM pool. A variety of management options may be specified including crop type, tillage, fertilization, organic matter (e.g., manure) addition, harvest (with variable residue removal), drainage, irrigation, burning, and grazing intensity.

Input data

We used the most detailed input data available at the county scale, the scale that we were modeling.

Soil data

Soil data was extracted from the Soil Survey Geographic Database (SSURGO) of the Natural Resources Conservation Service (NRCS). Estimates of soil physical parameters (e.g. texture, water-holding capacity, potential rooting depth) were estimated from the GIS version of the county soil survey maps, available within the SSURGO database. The SSURGO database is the digital form of the most detailed level of soil mapping done by the NRCS in the National Cooperative Soil Survey program.

Crop types and rotations

To determine which crops were grown where, we used the California Department of Water Resources (DWR) land-use GIS. This product is a GIS database with detailed maps of crop locations and crop type, derived from analyses of aerial photos and field surveys. Photos and surveys were taken in the mid 1990s, with the bulk acquired in 1994–1997. Crop classification in the DWR product is, however, variable because it sometimes indicates particular crops (corn, tomatoes, etc.) and other times broad crop categories (e.g. grains or vegetable crops). For Yolo County, this product was only available for 1997.

Since California has a very diverse agriculture, we had to limit the number of crops considered for this modeling exercise. Based on the United States Department of Agriculture (USDA) Census data from 2002 (Figure 1), we decided to model hay crops, corn for grain, winter wheat, tomatoes, safflower, and sunflower. For this study, we decided not to model any orchards (almonds and walnuts), because almost no data on biomass is available for calibration and validation of the model. Also, rice was not modeled due to the limited ability of DAYCENT to model methane emissions from inundated rice fields (Del Grosso et al., 2005). We assumed that most of the hay was alfalfa. After consultation with farm advisors and analysis of the 2000 to 2005 pesticide-use report data from Yolo County agricultural commissioners, we selected five typical rotations: tomato-wheat, corn-tomato-wheat, 4 x alfalfa-tomato-wheat, sunflower-tomato-wheat, and safflower-tomato-wheat. We calculated the probability of each field being in a specific rotation based on the acreages of these crops calculated from the DWR GIS. This was done using linear programming methods. To have a solution, it was necessary to assume that some fields were under continuous corn and continuous wheat (Table 1). For each of the field parcels in the DWR GIS, we randomly assigned a rotation according to these probabilities.

Management practices

Details on conventional management practices in the region (e.g., planting, fertilization, irrigation, weed control, and harvesting) were obtained from the Agronomy Research and Information Center (AgRIC; http://agric.ucdavis.edu/) and the cost and return studies available through the University of California Cooperative Extension (http://coststudies.ucdavis.edu/). The AgRIC is an outreach service, which provides research-based, comprehensive, and reliable information on current California agronomic cropping practices for alfalfa, corn, safflower, and small grains such as wheat. The cost and return studies contain details on agricultural inputs, planting and harvesting dates, and other operations for the six crops considered in this study. It is updated on a regular basis.

Next to conventional farming, we considered three alternative practices: winter cover cropping, organic, and reduced tillage. For the winter cover cropping, we assumed a leguminous cover crop. The organic treatment consisted of the addition of manure instead of inorganic fertilizer and winter cover cropping when appropriate. Information on the management of these alternative cropping practices was obtained from farm advisors and the long term research of agricultural systems (LTRAS) at Russell Ranch of the University of California, Davis. We considered all combinations of crops and management practices, except for winter cover cropping for winter wheat and alfalfa, and reduced tillage and organic practices for alfalfa, as the latter is grown continuously for four growing seasons. As an example, Table 2 contains the cropping event calendars for tomato.

Climate data

The DAYCENT model uses daily climate data (maximum and minimum temperatures, precipitation, wind speed, solar radiation, and relative humidity) to calculate soil microclimatic conditions. Spatially explicit climate data was extracted using the DAYMET model (www.daymet.org), developed at the Numerical Terradynamic Simulation Group of the University of Montana. This model uses a digital elevation model and daily observations from ground-based meteorological stations to produce a daily data set of temperature, precipitation, humidity, and radiation. It is available for the conterminous United States as 1 x 1 km grid cells for 1980 until 2003. There were 1817 of such 1 x 1 km grid cells available for Yolo County. However, due to computational constraints, we combined the 1 x 1 km grid cells for Yolo County into 274 3 x 3 km grid cells.

Modeling strategy

We modeled each separate unique combination of soils, crop type, and microclimate in the county. To do this, an overlay was created of the GIS soil information from SSURGO, the crop information from DWR, and the gridded climate data from DAYMET. This was done using ArcGIS Version 9. The result of this overlay was a database containing 11611 unique combinations of soils, crops, and climates. In the overlay procedure, a lot of very small polygons were created, which were not meaningful to the results at a regional scale. Therefore, due to modeling time constraints, we omitted the 25 % smallest fields, comprising only 5 % of the total area of the county.

A framework was developed to easily create all the input files necessary to run the DAYCENT model for each of these units. This framework also automatically collected the model results and calculated sums and averages of each of the output parameters of interest. This framework allowed us to easily carry out a large number of simulations over different gradients of soils, climates, and crops, and managements and interactions of these. The model itself was run on a 14-CPU UNIX cluster at the biocomputing center of the plant sciences department at the University of California, Davis.

Historical runs

We split the historical runs into three periods: (1) native grassland between 0 and 1869, (2) emergence of agriculture between 1870 and 1969, and (3) modern agriculture from

1970 until 1997. Since no meteorological data was available before 1980, we used climate data between 1980 and 2003 and repeated it. For the first period, a medium-productivity grassland was simulated, which grows from November until April. We included low-intensity grazing. The grazing affected 10 % of the live shoots and 5 % of the aboveground dead biomass. The floodplains of the Sacramento River and the Cache Creek were simulated as waterlogged, with unfavorable conditions for SOM decomposition. The period of 1869 years was sufficient to attain equilibrium in all the modeled C pools. The average modeled C input to the soil at equilibrium was 165 ± 13 g C m^{-2}.

In the second period, the emergence of agriculture, we simulated a rain-fed, low-input winter wheat system with minimal disturbance of the soil and a fallow every five years. From the beginning of the 20^{th} century, we introduced irrigation and diversified the crops to include summer-grown corn. Tomatoes were introduced in 1945. From 1950, inorganic fertilizer was used. We used historical records from the USDA to simulate the increase in the amount of fertilizer used.

In the last period, between 1970 and 1996, the randomly selected crop rotations were used (see section 3.2.2). From this period on, the intensity of soil disturbance was high. Similarly to the period before, the increasing use of fertilizer was simulated based on historical records.

Crop parameterization

Crop phenology and growing patterns were calibrated using county average yield data from the National Agriculture Statistics Service (NASS), biomass C and N data from two long-term agricultural experiments in the county (LTRAS and SAFS), and C allocation to shoots and roots and nitrogen dynamics data from various literature sources (Table 3). These values were confirmed with model results from the DSSAT/CERES plant growth model, using the climate and soil conditions of Yolo County (ICASA, 2004).

Current simulation and calculations

We simulated all modeling units for the period between 1996 and 2005 for conventional, reduced tillage, winter cover cropping, and organic practices. Per modeling unit, we calculated the relative change in yield, and the difference in CO_2 and N_2O emissions. The net difference in global warming potential (GWP) was calculated as follows:

$$\Delta GWP = \frac{44}{12}\Delta SOC + 296.\Delta\left[N_2O\right],$$

where ΔGWP is the global warming potential in Mg CO_2-eq ha^{-1}, ΔSOC the difference in soil organic C in Mg C ha^{-1}, and $\Delta\left[N_2O\right]$ the emission of N_2O in Mg N_2O ha^{-1}.

Results

Results of the historical runs

At the end of the first period of the historical runs (grassland with extensive grazing), all SOM pools were in equilibrium (Figure 3). Subsequent dryland agriculture increased SOM content by about 10 %, but the intensification of agriculture caused a 10 % loss in the middle of the last century. From around 1970, carbon contents increased again. In this period, a minor decrease in slow C was offset by an increase in passive C.

Historical wheat yields are well recorded. Therefore, they are useful to validate the historical crop yields predicted by the model. There was a good correspondence in wheat yields between 1870 and 2000 (Figure 4). Nevertheless, the model predicted a slow decrease in yields between 1880 and 1950 due to nitrogen depletion, whereas the historical data show yields to increase in this period, mainly because farmers gradually adapted new technologies such as irrigation and mechanized soil tillage. The modeled change in farming practices was much more abrupt.

There was a satisfactory relation between modeled SOC contents in 1996, and the SOC contents inferred from the SSURGO digital soil survey maps (Figure 5). In addition, the model was able to predict county average yields quite well. However, within a crop, yearly differences were less well modeled, indicating that the inter-annual variability due to weather conditions or crop pests was not as well simulated.

Results of the current simulations

Our simulations indicated that reduced tillage management had minimal effect on yields. Reduced tillage led to an increase in GHG emissions for wheat (about 0.3 Mg CO_2-eq ha^{-1} yr^{-1}) and reductions for the other crops (Table 4). The reductions were similar for corn, safflower, and sunflower and averaged around 1 Mg CO_2-eq ha^{-1} yr^{-1}. The reductions were larger for tomatoes (3.6 Mg CO_2-eq ha^{-1} yr^{-1}). All crops showed a net decrease in N_2O

emissions. However, there was no consistent trend in the contribution to the GWP of CO_2 versus N_2O.

Winter cover cropping led to small reductions in yield of about 3% for tomatoes, whereas the other crops were minimally affected. For all crops under winter cover cropping management, there was a reduction in GHG emission ranging from 0.7 to 3.3 Mg CO_2-eq ha^{-1} yr^{-1}. Winter-grown wheat, within a winter cover cropping rotation, was associated with a decrease in GHG of 0.2 Mg CO_2-eq ha^{-1} yr^{-1}. Contributions to the GWP were mainly coming from increases in SOC (Table 4). For almost all crops (except sunflower), there was a net increase in N_2O emissions, ranging from 0.07 Mg CO_2-eq ha^{-1} yr^{-1} for corn to 051 Mg CO_2-eq ha^{-1} yr^{-1} for safflower.

Implementing organic management reduced sunflower, tomato, and wheat yields by 3 – 4 %; other crop yields were even less affected. GWP decreased for all crops. This decrease was largest for corn and sunflower (4.8 Mg CO_2-eq ha^{-1} yr^{-1}), followed by tomatoes (4.2 Mg CO_2-eq ha^{-1} yr^{-1}), safflower (3.1 Mg CO_2-eq ha^{-1} yr^{-1}), and wheat (1.2 Mg CO_2-eq ha^{-1} yr^{-1}). These reductions were both due to an increase in SOC and a decrease in N_2O emissions, i.e. 16 to 57 % of the reduction was related to N_2O (Table 4).

We found that low input systems did not affect yields, except for safflower. The GHG emissions decreased between 0.2 and 2.3 Mg CO_2-eq ha^{-1} yr^{-1}. All of this decrease was due to reductions in N_2O emissions.

Discussion

Greenhouse gas emissions are controlled by biogeochemical processes in the soil and rhizosphere such as nitrification, denitrification, and aerobic decomposition. These processes are complex and challenging to quantify as they are influenced by an array of factors including climate, plant physiology, soil physical and biological properties, and land use and management (e.g. crop type, irrigation, fertilization, cultivation, and residue management). Since land use and management can be controlled to minimize greenhouse gas emissions, the possibility exists for agriculture to participate in the carbon market. To test the feasibility of agriculture participating, a detailed analysis of yield changes and mitigation potentials is essential. Using the biogeochemical model DAYCENT, we simulated every single unit of 2000 unique crop rotation and soil-type units within Yolo County, Calif., for four alternative management options: reduced tillage, winter cover cropping, organic, and low-input managements.

Comparison of Emission Values to the Literature

Changes in yield

Effects on yields of these practices were minimal. Highest reductions in yields (a reduction of only 4%) were simulated for tomatoes under organic management. This coincides with what is reported in the literature. For example, Miguez and Bollero (2005) found that when organic fertilizer was applied in winter cover cropping systems, there was no difference in corn yields. Similarly, organic farming did not lead to consistent trends in wheat yields in a study in a Mediterrean climate (Beria et al., 2003). The same was found for tomatoes in California (Drinkwater et al., 1995). Cover cropping frequently increases yields: in a review, Snapp et al. (2005) reports yield increases up to 15%. The modeled lack-of-yield response might be overly optimistic, since the DayCent model does not take all limitations of crop growth into account. For example, the model cannot predict a possible higher aptitude for diseases and pests under certain cropping systems (Karungi et al., 2006), neither does it simulate the decreased seedling growth when a crop is sown within dead biomass, as is the case for reduced tillage. In addition, the model version that we used did not take into account phosphorus or potassium. Yields might decrease under organic farming due to a decrease in P-availability.

It may seem surprising that even for the low-input treatment, in which 25% less fertilizer is applied, almost no reduction in yields were noted. However, this indicates that the conventional amount of fertilizer applied in the county is above what is actually needed for crop growth. Over-fertilization is a common practice due to the low price of nitrogen fertilizer and the minimization of the risk of yield reduction due to nitrogen limitation (Cassman et al., 2002).

Changes in carbon

Our average simulated differences in soil organic carbon (SOC) corresponded with literature values. In no-tillage systems, the average change in SOC (0.5 Mg CO_2-eq ha^{-1} yr^{-1}) is in the same order of magnitude as the values reported by Franzluebbers (2005) (1 Mg CO_2-eq ha^{-1} yr^{-1}), and the review of Six et al. (2004) (0.8 Mg CO_2-eq ha^{-1} yr^{-1}) for a 10-year-old, no-tillage system in a humid climate. We simulated an average SOC increase for winter cover cropping systems of 2.1 Mg CO_2-eq ha^{-1} yr^{-1}, close to the average SOC increase for no-tillage winter cover cropping systems reported by Franzluebbers (2005) (2 Mg CO_2-eq ha^{-1} yr^{-1}).

The difference between the organic and winter cover cropping systems was the use of manure instead of inorganic fertilizer. Therefore, the difference in SOC change between these two treatments (0.5 Mg CO_2-eq ha^{-1} yr^{-1}) corresponded with the change in SOC due to manure addition. On average, the organic practice that we modeled added 1 Mg C ha^{-1} to the soil. Therefore, the manure C to SOC conversion rate was about 14%. This value is very close to the conversion rate of 17 % based on field measurements from Franzluebbers (2005).

Changes in N_2O

For reduced tillage, Six et al. (2004) reported changes in N_2O emissions between 1.2 and 0.2 Mg CO_2-eq ha^{-1} yr^{-1}, depending on the duration of the experiment. These values corresponded quite closely to our simulated N_2O emissions, varying between -1.0 and -0.1 Mg CO_2-eq ha^{-1} yr^{-1} for the different crops.

There are no cumulative annual N_2O emission rates available for California agroecosystems with which we could compare our model results. We strongly suspect that the warm climate together with the frequent irrigation for all crops leads to great N_2O emissions, which can be significantly reduced by alternative management practices.
We modeled a decrease in N_2O emissions from organic farmed soils. It has been reported that organic farmed soils contain less nitrate than conventionally farmed soils (van Diepeningen et al., 2006), which would also lead to less N_2O emissions, as we modeled.

Potential for Greenhouse Gas Mitigation

The highest reduction in GHG emissions was simulated for organic cropping systems, followed by winter cover cropping, reduced tillage, and low-input systems. However, the capacity of a soil to store carbon is limited (VandenBygaart et al., 2002; Six et al., 2004), and if the proper soil management is not maintained, all the carbon that was sequestered in the soil will be released again to the atmosphere. In contrast, reductions in N_2O emissions are permanent (VandenBygaart et al., 2004). For example, the winter cover cropping management option sequestered a significant amount of C. However, this was mainly due to an increase in SOC; N_2O emissions even increased. Winter cover cropping, therefore, seems only a viable option to curb GHG mitigation in the short term (i.e., 10 – 20 years, when C equilibrium is reached). However, by combining use of organic fertilizer (i.e. manure) together with winter cover cropping, organic systems are associated with both a net increase in SOC and a decrease in N_2O emissions, each accounting for about half of the total GWP reduction. This decrease in N_2O emissions was especially pronounced for corn and safflower. Organic farming is, therefore, in general a more permanent option to reduce GHG emissions and a better solution in the long term. Although the potential and efficiency of organic cropping systems is high, its applicability is limited and dependent on the amount of manure available.

Although the GHG mitigation was smaller for reduced tillage compared to winter cover cropping and organic systems, there was a significant net decrease in N_2O emissions for all crops. This decrease contrasts the review of Six et al. (2004) in which it was concluded that N_2O emissions increase initially after conversion to no tillage. However, this study does not include data from Mediterranean climate zones. This decrease in N_2O emissions was greatest for corn and tomatoes; for tomatoes, there was also a large increase in SOC. As a result, adopting reduced tillage in corn and tomato systems is beneficial for GHG mitigation.

The low-input system had the least overall potential to decrease GHG. Nonetheless, nearly all of this decrease is due to a decrease in N_2O emissions. Decreasing N_2O emissions in low-input systems indicate that conventional systems are over fertilized and that the surplus of mineral N which is not taken up by the crop is high. This surplus might be denitrified when there is a supply of C-substrate and sufficient moisture (McSwiney and Robertson, 2005). In addition, costs to implement this strategy will be similar or even less than the conventional system. Therefore, low-input systems seem to be an efficient way to permanently mitigate GHG emissions, regardless of the duration of the practice.

In conclusion, use of winter cover cropping is a short-term solution for C-sequestration, but might be problematic in the long term (> 50 years), when the soil reaches a steady state for soil carbon. Organic systems are more efficient in the long term, especially when corn is included in these rotations. Reduced-tillage systems are especially advantageous in systems that have corn and tomatoes included in their rotation. Low-input systems are very efficient in reducing N_2O emissions for every crop at any time scale.

Clearly, the success of a carbon-trading system is dependent on the quality of estimates of greenhouse gas emissions at a field level. It is well known that of all the greenhouse gases, the variability around predictions of N_2O emissions is most problematic. The variability of N_2O emissions is both spatial (range of meters) and temporal (range of hours). Winiwarter and Rypdal (2001) concluded that the uncertainty around N_2O emissions of agriculture is the main source of uncertainty in the national inventory of all greenhouse gases from all sources. This variability is incurred by the dependence of nitrification and denitrification on moisture levels in the soil which are highly variable. In addition, the amount of mineral N available in the soil for nitirification and denitrification is highly dependent on crop N demand. Rypdal and Winiwarter (2001) estimated that the uncertainty (quantified as 2□) around agricultural N_2O emissions is about 120 %, while this is only 36% for CH_4 and 3% for CO_2. These findings illustrate the need to include a sound error analysis in further research.

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Table 1. Probabilities of a field being in a specific rotation based on its DWR crop designation in 1997.

DWR crop designation in 1997	tomato wheat	corn tomato wheat	4 x alfalfa tomato wheat	sunflower tomato wheat corn	safflower tomato wheat corn	continuous wheat	continuous corn
wheat	0.05	0.09	0.15	0.09	0.44	0.19	0.00
tomato	0.06	0.11	0.19	0.11	0.54	0.00	0.00
corn	0.00	0.07	0.00	0.07	0.34	0.00	0.53
alfalfa	0.00	0.00	1.00	0.00	0.00	0.00	0.00
safflower	0.00	0.00	0.00	0.00	1.00	0.00	0.00

Table 2. Event calendar of a tomato growing season for four management options: conventional (CONV), reduced tillage (RT), winter cover cropping (WCC), and organic (ORG).

	Management			
event	CONV	RT	WCC	ORG
herbicide in spring		15 Jan		
field cultivator (tandem disc)	15 Jan	15 Feb		
moldboard tillage	15 Feb		2 Apr (incorporates WCC)	2 Apr (incorporates WCC)
pre-irrigation	8 Apr	8 Apr	8 Apr	8 Apr
manure addition				15 Apr, 750 kg C ha-1, 107 kg N ha-1
planting day	15 Apr	15 Apr	15 Apr	15 Apr
starter fertilization	13.5 kg N ha-1	13.5 kg N ha-1	13.5 kg N ha-1	
nr. of growing season cultivations	5	5	5	5
nr. of irrigation events	7	7	7	7
fertilization	7 May, 168 kg N ha-1	7 May, 168 kg N ha-1	7 May, 168 kg N ha-1	
fertilization	14 May, 6.2 kg N ha-1	14 May, 6.2 kg N ha-1	14 May, 6.2 kg N ha-1	
harvest	15 Sep	15 Sep	15 Sep	15 Sep
incorporate biomass			22 Sep	22 Sep
moldboard tillage	30 Sep		29 Sep	
plant legume WCC			4 Nov	4 Nov

Table 3. Critical plant parameters.

	Yield (T ha^{-1})	C:N ratio of harvestable part	C:N ratio of aboveground unharvestable part	C:N ratio of roots	harvest Index	shoot to root ratio
alfalfa	14.76	NR	16	16	0.30	1.10
corn	11.6	30	60	55	0.53	4.35
safflower	2.6	18	38	75	0.25	4.00
sunflower	2.3	12	40	75.5	0.27	6.60
tomato	75.1	18	20	35	0.57	4.18
wheat	5.4	22	90	34	0.53	4.55

Table 4. Average relative changes in yield, absolute differences in global warming potential (GWP), and contribution to the GWP by CO_2 and N_2O when changing from conventional management to reduced tillage, winter cover cropping, organic practices, or a low-input system. This is calculated for six common crops in Yolo County, Calif., for the period 1997-2006.

	Yield	GWP	CO2	N2O
	(%)	(kg CO2-eq ha-1 yr-1)	Contribution to GWP (%)	
		Reduced tillage		
alfalfa	-0.14	-58	81	19
corn	-0.04	-1080	-5	105
safflower	-0.51	-774	32	68
sunflower	0.00	-1140	90	10
tomatoes	-0.98	-3609	75	25
wheat	0.07	266	123	-23
		Winter cover cropping		
alfalfa	1.60	-624	125	-25
corn	-1.00	-1068	106	-6
safflower	-0.70	-694	174	-74
sunflower	-1.22	-3293	99	1
tomatoes	-3.24	-2551	115	-15
wheat	-0.01	-168	-23	123
		Organic		
alfalfa	1.30	-632	116	-16
corn	-0.92	-4815	44	56
safflower	-1.19	-3060	49	51
sunflower	-2.47	-4743	72	28
tomatoes	-3.99	-4212	84	16
wheat	-3.45	-1159	43	57
		Low input		
alfalfa	-0.28	-9	-45	145
corn	-0.17	-1732	0	100
safflower	-2.31	-970	-7	107
sunflower	-0.11	-839	-1	101
tomatoes	-0.46	-1018	-2	102
wheat	0.00	-169	-5	105

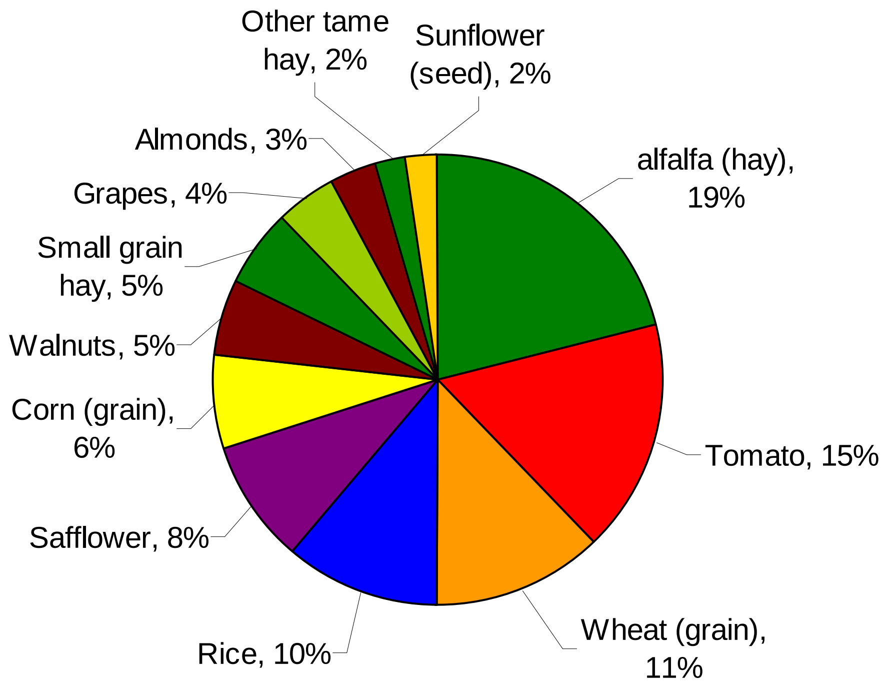

Figure 1. Relative surface area of crops in Yolo County, adapted from the 2002 USDA Agricultural Census

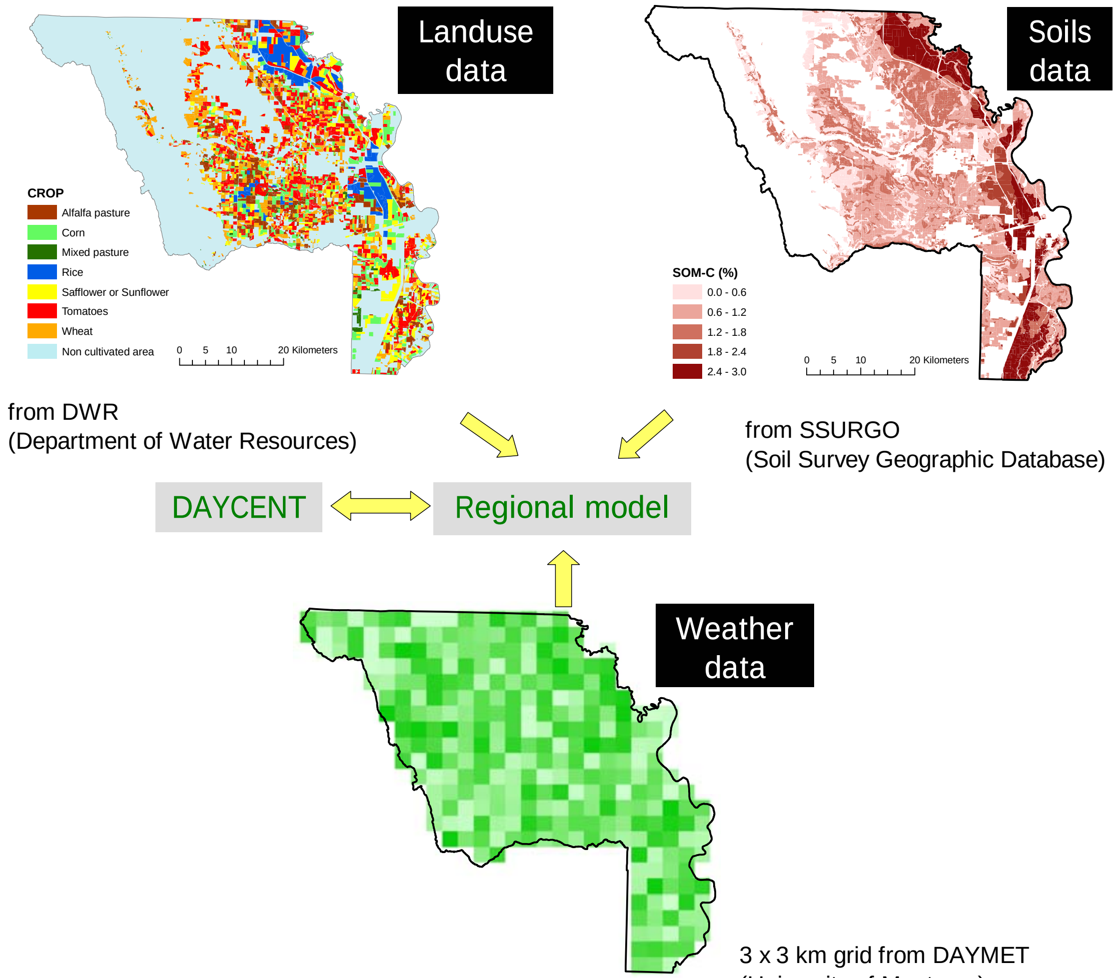

Figure 2. Data sources for the modeling strategy

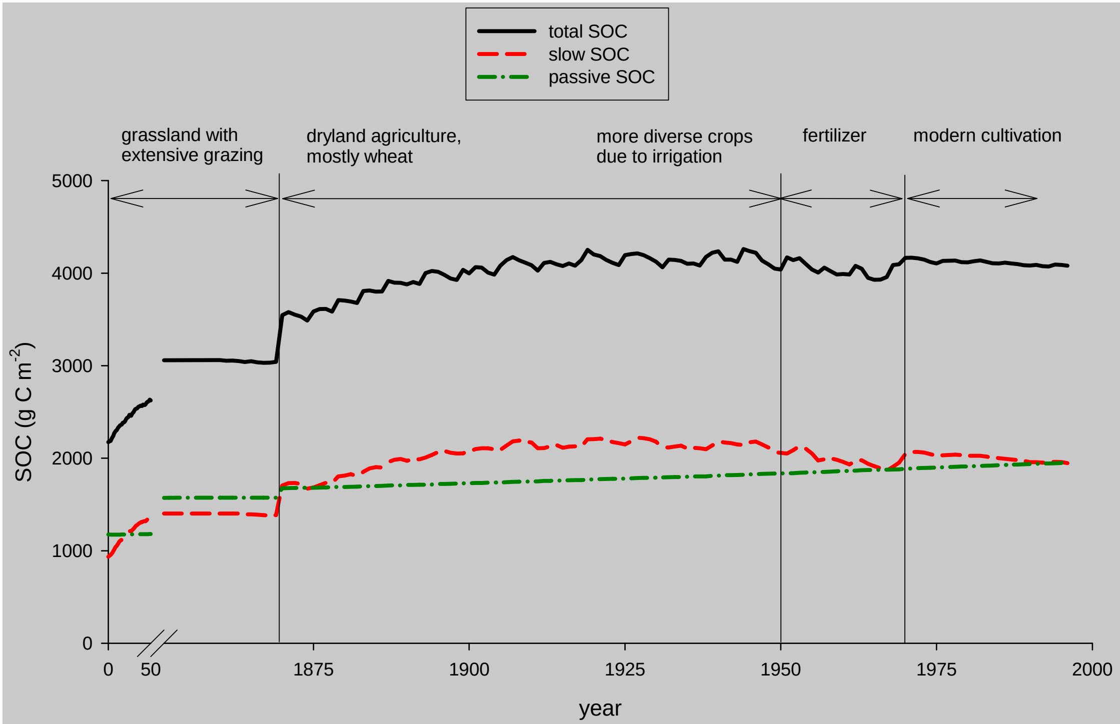

Figure 3. Typical modeled evolution of SOC in Yolo County between the years 0 and 1996.

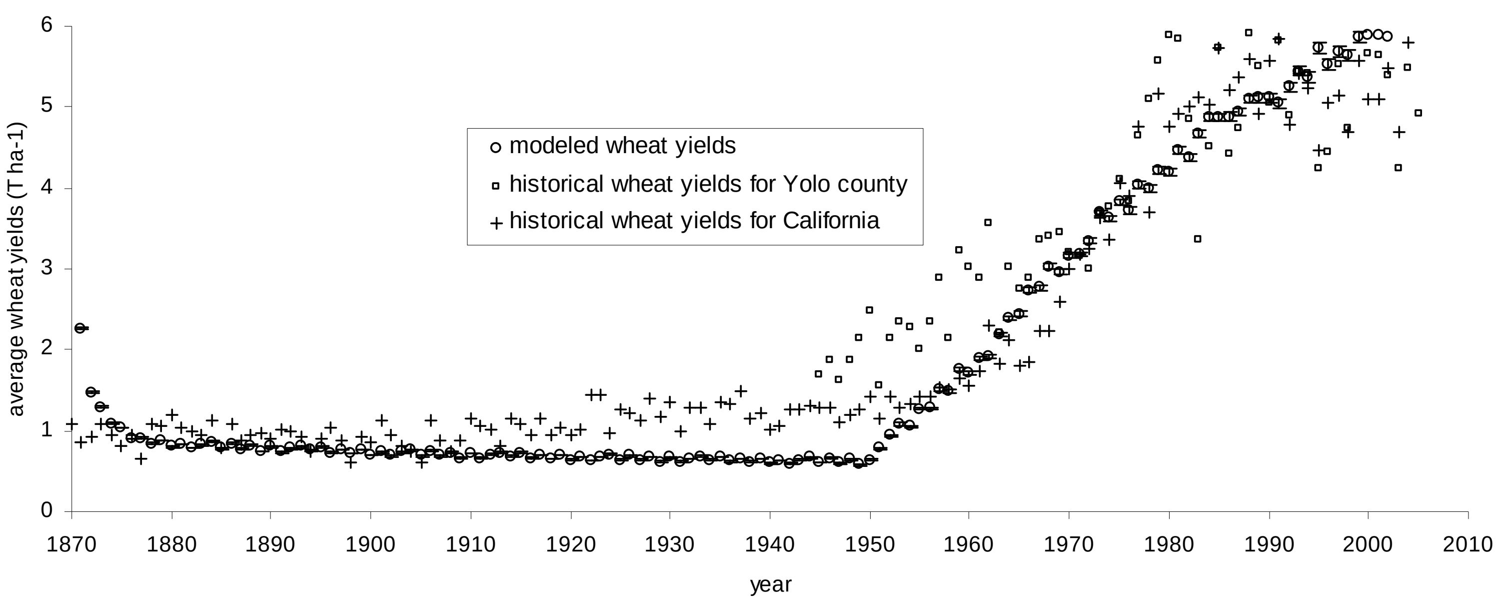

Figure 4. Modeled versus historical wheat yields.

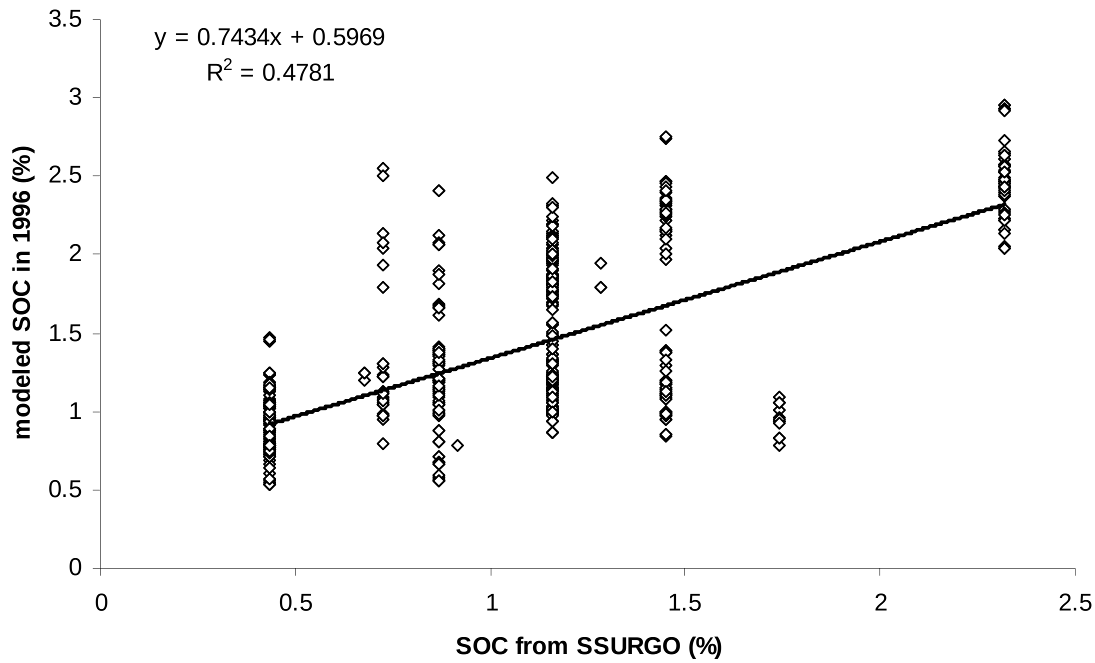

Figure 5. Modeled soil organic carbon (SOC) in 1996 versus SOC from SSURGO.

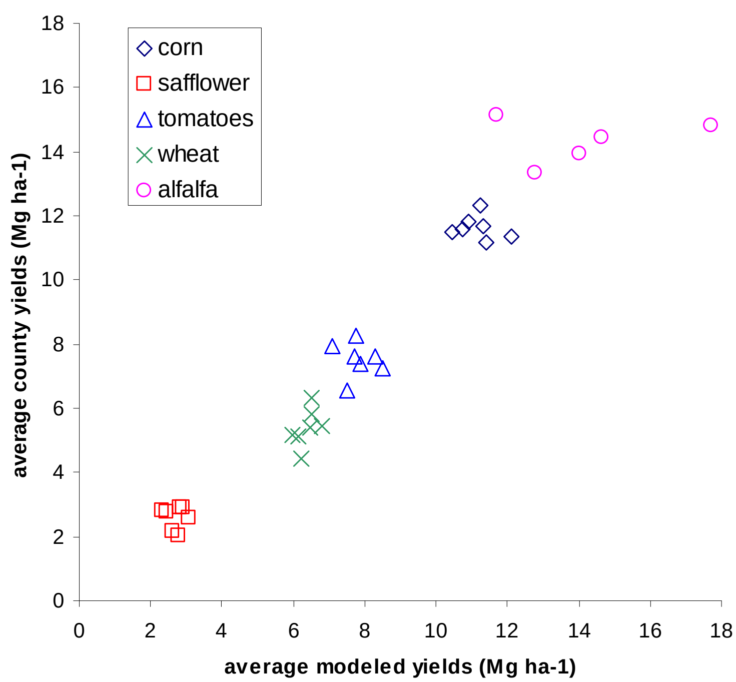

Figure 6. Modeled versus county average yields.

USE OF SUBSURFACE DRIP IRRIGATION, CONSERVATION TILLAGE AND COVER CROPPING TO REDUCE GREENHOUSE GAS EMISSIONS IN CALIFORNIA AGRICULTURE

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Abstract

The threat of water scarcity in the western United States and the contemporary issue of trace gas emissions from agriculture are emerging issues. California row-crop agriculture has developed using some of the most intensive practices including deep and frequent tillage and the need to maintain a bed and furrow system for furrow irrigation (FI). California row-crop agriculture has been immensely successful producing more than half of the fruit and vegetables for U.S. consumption. Our objective was to evaluate the integrated use of subsurface drip irrigation (SDI), tillage reduction (TR), and cover cropping (CC) to address greenhouse gas (CO_2 and N_2O) emissions. We hypothesized that CO_2 and N_2O will be lower in SDI compared to FI, due to less wetting and synchronization of nutrient demand with SDI. CO_2 flux for the entire growing season was 3.2% lower in the combined SDI treatments than in the combined. Total CO_2 emission from the SDI treatments is approximately 2 to 4% lower compared to the FI. Agricultural management alternatives show promise in addressing emerging water and trace gas issues in California agriculture. Future efforts will address implementation of these practices into intensive management regimes to maintain productivity and sustainability of the systems.

Key words: conservation farming systems, irrigation, conservation tillage, cover cropping

TILLAGE, SOIL BIOTA, AND SOIL CARBON STORAGE

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Abstract

Both tillage reduction and addition of crop residues can increase soil C storage. In vegetable crop systems, however, no-tillage and cover cropping can decrease crop yields in California. To assess these tradeoffs, the following treatments were compared for one year in a tomato-legume rotation: no tillage + continuous cropping, no tillage + fallow, standard tillage + continuous cropping, and standard tillage + fallow. No tillage + continuous cropping resulted in significant changes in the surface layer (0-5 cm), compared to the other treatments: higher microbial biomass C, more fungi as indicated by ergosterol and phospholipid fatty acid (PLFA) analysis, higher soil NO_3^- in summer, and higher pH, K^+, and Olsen P at the end of the experiment. Total soil C (g C m^{-2} at 0-30 cm depth) was least with standard tillage + fallow, which is the typical cropping system. Nematode biomass in the 0-30 cm profile was marginally correlated with total aboveground plant biomass. The soil food web, as indicated by the nematode fauna, did not become more complex with no tillage + continuous cropping, contrary to expectations, possibly due to the lack of colonization by higher trophic-level organisms. Plant aboveground biomass, except for weeds, was reduced by no tillage. By decreasing disturbance, and increasing fungi, no tillage + continuous cropping appears to have accelerated soil C storage, but it will be necessary to improve management to increase crop yields in this Mediterranean-type climate.

Key words: cover crops, nematodes, no-tillage, soil microbes, soil carbon, conservation farming systems

CONSERVATION TILLAGE PRACTICES IN CALIFORNIA

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Abstract

Conservation tillage (CT) is not widely practiced in California's primary production valleys today. Current estimates of CT acreage in California are less than 2% for major crops such as corn, cotton, forages, and tomatoes. A range of economic and environmental drivers have, however, resulted in interest in alternative tillage systems throughout the state and local networks of farmers, equipment companies, and private sector agriculture services. Hence, researchers are now beginning to develop and refine CT cropping systems for these crops. The University of California/ USDA Natural Resources Conservation Services/ California Association of Resource Conservation Districts CT Workgroup has grown to more than 540 members in the past five years. More than 70 CT demonstration evaluations have been conducted during this time, and a CT Annual conference series has attracted more than 1200 participants since 1998. A wide range of CT approaches are being explored according to specific environmental and crop rotation context of a particular region. Most current CT systems tend to be "reduced tractor pass" in nature, rather than no till. In addition to cutting production costs, improving air quality, and reducing surface water runoff are important potential benefits of CT production systems currently being investigated in California. While a small number of California farmers have adopted CT practices, the vast majority are currently not using them at this time. The CT workgroup currently is addressing the broad range of barriers to more widespread adoption of CT in California.

Key words: conservation tillage, California, cropping systems

Introduction

The importance of minimizing soil erosion and conserving soil resources first came to national attention in the United States during the "Dust Bowl" period in the early 1930's when the combination of intensive tillage, drought, crop failure, and wind-driven erosion of millions of acres of farmland occurred in the Great Plains region of the U.S. (Coughenour and Chamala, 2004). In the decades following, a number of reduced soil disturbance or conservation tillage (CT) production systems emerged in the Midwest and the southeast U.S. to address soil-loss concerns. Because of the important role that surface cover or roughness has in mitigating soil erosion losses, the concept of CT during this time eventually became linked with the specific management goal of maintaining at least 30% crop residue on the soil surface after planting, and this has been the primary characteristic used in USDA definitions of CT. Reduced soil disturbance, however, is a key element in these definitions.

Most CT systems are based on one of three reduced-soil-disturbance planting systems: no-till, ridge-till, or strip-till. In no-till, or zero-till, the only tillage that is used is the soil disturbance in a narrow slot created by coulters or seed openers (MWPS – 45, page 6). The soil surface is thus generally left undisturbed except at the time of planting. Ridge-till is a reduced-disturbance planting system in which crops are planted and grown on ridges formed during the previous growing season and by shallow, in-season cultivation equipment. Ridge-till planters sweep away or shear off residues and soil in the seed line but do not disturb much of the inter-row soil surface. In strip-till, coulters cut residues ahead of subsoiling shanks that loosen the soil from a few to as many as 14 inches ahead of a planter. In each of these CT systems, only a small percentage of the soil surface is disturbed, unlike the "broadcast" tillage or land *preparation* operations typically used in conventional tillage systems.

In California, however, where use of the term "conservation tillage" is much more recent, a broader paradigm has developed that focuses more on reducing the overall number of tillage passes rather than on strictly preserving surface residues, in part to reduce fuel use and dust emissions. Thus, CT in California currently refers to a wide range of production practices that deliberately reduce primary, intercrop tillage operations such as plowing, disking, ripping, and chiseling. Under this definition, residues are managed in a variety of ways to permit efficient planting, harvesting, and pest control. From this perspective, any production system that significantly reduces tillage operations and conserves resources (generally by more than 40% relative to what was done in the year 2000) is defined as "conservation tillage" in California.

Benefits of CT

The success of CT in maintaining yields while reducing soil erosion has added to its popularity. Equipment innovations, herbicides, and herbicide-tolerant crops, as well as widespread farmer and researcher experience, have contributed to the success of CT. In addition to reducing soil loss by erosion and runoff, CT systems have a number of other attributes that add to their appeal to producers. Because they aim at reducing primary, intercrop tillage operations such as plowing, disking, ripping, and chiseling, fewer tractor operations are used. The consequent reduced fuel use often improves farm profitability. In addition, NOx and dust generation are reduced (Baker et al., 2005) and CO_2 losses may be decreased (Reicosky, 1997). CT systems may also conserve soil water by reducing evaporative and surface runoff losses, thereby enabling the intensification and diversification of cropping systems (Beck, 1990; Freebairn et al., 1993). Possible benefits of CT are summarized in Table 1.

Table 1. Possible benefits of conservation tillage

- saves fuel	- saves machinery
- increases soil moisture	- increases soil organic matter
- saves soil	- sequesters carbon
- saves time	- reduces dust emissions
- saves labor	- reduced surface water (sediment, nutrient and pesticide) runoff

Governmental Incentives for Adopting CT

The 2002 U.S. Farm Bill provides incentives for farmers to voluntarily address environmental resource concerns using production practices such as CT. Such practices are approved through local work group initiatives in United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) county offices. The NRCS Environmental Quality Incentives Program (EQIP), for example, provides technical assistance and cost-share incentive payments to assist producers with environmental conservation improvements such as the use of CT on their farms. In 2003, for the first time in California, CT was approved as a statewide “cost-share” EQIP practice. In the past two years, a number of EQIP CT contracts have been implemented in the San Joaquin Valley, aimed primarily at air quality improvement.

Adoption of CT in California

Since 1997, more cropland acres have been farmed nationwide using CT practices than standard tillage practices (CTIC, 2004). However, despite the apparent attractiveness of reduced tillage or CT systems, the NRCS estimates that less than one percent of row crop production acreage in California's Central Valley is currently farmed using CT practices (CTIC, 2004). Reasons for this low rate of CT adoption in California are generally thought to result from a lack of CT equipment being available locally, inexperience with CT techniques, the predominance of surface or gravity irrigation systems in California, and the fact that tillage-intensive systems have been developed here for several decades and are generally quite productive.

The CT Workgroup

To respond to needs for information on reduced-tillage production alternatives in California, the UC Division of Agriculture and Natural Resources and the USDA NRCS Conservation Tillage Workgroup were established in 1998. Goals of the CT workgroup are to develop knowledge, exchange information, and coordinate research and extension education programs related to CT production alternatives in California. From a handful of academics, the workgroup has grown to more than 650 UC, USDA ARS and NRCS, farmer, public agency, private industry, and non-governmental group members and has been active at more than 60 research and demonstration sites throughout the state. The growing body of experience that workgroup members have acquired during this time includes CT production systems evaluations for cotton, wheat, tomatoes, melons, corn, beans, lettuce, and cover crops. The CT workgroup currently has a technical service provider agreement with the NRCS to provide support and education related to CT systems and has partnered with more than 30 farmers in a variety of CT evaluations throughout the Central Valley.

CT Workgroup Research and Education Activities

Workgroup-sponsored CT conferences have been held annually in Five Points and Davis, Calif., beginning in 1998 with sessions focusing on relationships between soil organic matter, tillage, and soil quality. The 2000 conference highlighted CT success stories from around the US. Our 2001 conferences focused on CT equipment demonstrations; our 2002 events dealt with researcher and farmer innovation; the 2003 sessions dealt with the current state of CT in the Valley; CT2004 again highlighted CT equipment; and CT2005 was organized as tours to innovative CT tomato, cotton, and diary forage farms. Participant feedback reveals increasing interest in CT alternatives and indicates an expectation that CT will become more widely used throughout the state once successful examples are demonstrated (Table 2). Recent informal polling of the workgroup's farmer members suggests that unlike other regions where CT systems have been adopted, primary motivations for these alternatives in California include cutting production costs, storing carbon in the soil to improve soil quality, weed management using dense crop residues or over-the-top herbicides for organics, and growers using herbicide-tolerant crops, respectively, and generally conserving society's "common assets"- our soil, water and air resources. Examples of the types of CT studies currently being conducted by the workgroup are briefly described in Table 2.

Table 2. Participant responses to post-CT1998, 2000 and 2003 conference questionnaire question "What do you think about the future adoption of the various conservation tillage practices in California presented at this Conference?" Numbers in parentheses are the percentages of respondents.

	1998 (n = 54)*	**2000 (n = 79)**	**2003 (n = 48)**
CT practices will not be widely adopted in California		3 (4)	1 (2)
Adoption of CT will likely be on a very limited scale	11 (20)	11 (14)	3 (6)
CT may become more widely adopted if successful examples are demonstrated	36 (67)	45 (57)	21 (44)
It is inevitable that CT will have a far wider role in California	7 (13)	20 (25)	23 (48)

*Number of responses

A variety of evaluation activities have been initiated to develop information on reduced-tillage production options. These studies have focused on different aspects of CT systems including 1) opportunities and issues related to integrating cover crops in CT production systems, 2) developing and refining the ability to produce single crops using reduced-till approaches, and finally, 3) integrating CT principles throughout various sequences or rotations of crops. Much of this early research was done in standard research and extension center small-plot work (Herrero et al., 2002a; Herrero et al., 2002b). This preliminary work was essential for subsequent larger scale trials that have been done in conjunction with farmers. Figure 1 indicates the crops and locations where CT practices have been evaluated.

Following these initial small-scale studies, and as the CT workgroup acquired more reduced-till equipment, several larger scale demonstrations of CT systems were initiated with partner farmers. Farmers actually initiated a number of these trials, asking for implementation support and offering land, facilities, and labor to workgroup partners. Several of these farmer demonstrations have been developed into case studies documented in the CT workgroup 2003 conference proceedings and on the CT workgroup Web site (http://groups.ucanr.org/ucct/), and others have been prepared as peer-reviewed publications (Mitchell et al., 2006).

The CT workgroup, in conjunction with the California NRCS State Agronomist, also initiated a survey to track trends in reduced-tillage practices throughout the Central Valley. Local CT workgroup members conducted this survey for the first time in 2004. Data on CT acreage for major Central Valley crops were collected from local NRCS staff, UC advisors, and private sector CT workgroup members, and will be provided every two years to the Conservation Technology Information Center in Lafayette, Ind., for compilation in their national data base on CT. In this survey, a new CT category, "≥40% reduction in overall tillage relative to standard tillage practices for a given crop in the year 2000," was used in addition to the more conventional CT classifications of no-till, strip-till / ridge-till, and mulch-till. The rationale for including this category was to track "reduced-pass" practices that may achieve conservation and economic goals, but that do not necessarily conform to the

"30% or more residue" requirement of the classic USDA CT definition. Results of this 2004 survey are presented in Table 3. In general, both the classic CT and the minimum-till (>40% reduction in tillage passes) systems currently represent about 2% of the total acreage for the crops and counties surveyed, with more acreage under minimum tillage than under CT.

The CT Workgroup has also instituted an annual CT Farmer Innovator Award Program to acknowledge and honor pioneering leaders in the development of CT systems in the California. workgroup

Table 3. 2004 California Conservation Tillage Acreage Survey for tomatoes, cotton, edible dry beans, silage corn, grain corn, and small grains for grain, hay, and silage.

	Conservation Tillage				Minimum Tillage	Conventional Tillage	
	> 30% Residue Cover after Planting				>40% reduction in total passes	< 30% Residue Cover after Planting	
Crop	No Till	RT/ST[1]	Mulch Till[2]	Subtotal			Total Acreage
Fresno County	2,250	260	150	2,660	20,830	534,411	537,071
Kern County	0	0	0	0	23,200	295,616	295,616
Kings County	0	0	0	0	2,708	370,281	370,281
Madera County	0	0	0	0	800	122,163	122,163
Merced County	485	0	0	485	3,735	320,071	320,556
Sacramento	650	0	0	650	2,610	75,557	76,207
San Joaquin	505	0	0	505	2,450	271,589	272,094
Tulare County	1,375	430	0	1,805	8,280	381,546	383,351
Yolo County	0	0	51,000	51,000	0	138,683	189,683
Total	5,265	690	52,150	57,105	54,913	2,590,235	2,647,340

[1]Ridge-till/Strip-till
[2]Mulch-till is defined by the CTIC as "full-width" tillage usually requiring only one to three tillage passes. After planting, at least one-third of the surface remains covered with residue.

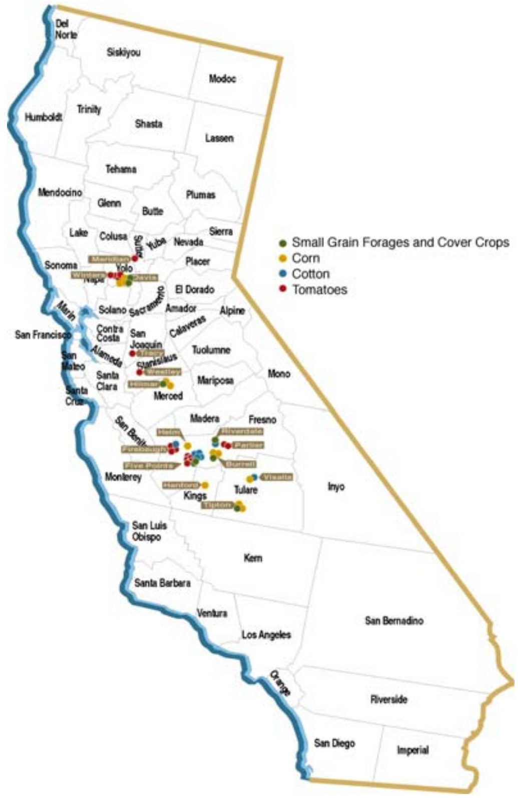

Figure 1. Locations of Conservation Tillage Workgroup's corn, cotton, tomato, and small grain forage research and demonstration evaluation sites, 2000 – 2005. Members have visited farmers and researchers in Alabama, South Dakota, Iowa, South Carolina, Texas, Oregon, and Arizona in an effort to learn about successful CT systems.

Future of CT in California

Development of successful CT systems in California, as in other regions, requires a "systems" orientation and will not result from the introduction of a single technology or practice (Coughenour and Chamala, 2004). New paradigms for rotations, planting, fertility, irrigation, and pest management systems are needed and are currently beginning to be developed and shared through connections among farmers, the private sector, non-governmental organizations (NGO's), and "information flow" people from the University of California and the USDA NRCS. Several "local networks" of CT cropping innovation (Coughenour and Chamala, 2004) have been established and are currently being facilitated by the CT eorkgroup. Many questions remain to be answered, however, with respect to the extent to which CT will be pursued in California: How might CT practices be developed for

California's very diverse cropping systems? Can CT contribute to water conservation in California? Will CT improve soil, water, and air resource quality? What will be the long-term impacts of CT on labor and farm economies? To date, the CT Workgroup has been pivotal in initiating research aimed at answering these questions. Its success has resulted from several factors, including its timeliness in responding to the need for information on reduced-tillage options within California's current production systems and economic environment, the encouragement of the university DANR and the USDA NRCS, and perhaps most importantly, the recognition that public-private partnerships result in diversified teams that are an effective means for innovative program development and a dynamic organizational structure for the integration of research and education leading toward improved cropping systems.

Refining CT Tomato Production

An example of the development of information on CT systems in California is seen in our work with tomatoes. Since 1999, we evaluated CT and cover-cropping (CC) practices for tomato production in an eight acre field in Five Points, Calif. The objective of this work has been to compare standard till (ST) with and without (NO) winter cover crops and conservation tillage with and without cover crops in terms of economics, productivity, soil properties, and dust emissions through a tomato – cotton rotation. The study field was divided in half to allow both crops to be grown in each year. A summary of the first five years of this work is presented here.

The standard-tillage systems have been managed as customarily done in the west-side San Joaquin Valley region. Beds are disked and reformed following harvest of each crop. Prior to tomatoes, the beds are also shaped with a power incorporator. The standard-till cover crop system uses a triticale/rye/vetch "green manure" approach, with the cover crop disked each spring before reshaping beds and establishing the summer crops.

The CT systems use about 50% of the overall tillage or soil disturbance operations as the ST systems. Tomatoes are "no-till" transplanted and cotton is no-till seeded into beds that haven't been worked or moved since the beginning of the study-except for a shallow root undercutting following cotton harvest for pink bollworm management compliance. Tomato beds have been quite "rough" following the one-pass, fall cotton-stalk management operation and are "re-readied" using furrow sweeps at the time of transplanting and during in-season cultivations. In the CT cover crop systems, the cover crop is sprayed with glyphosate, chopped, and left on the soil surface as a mulch before transplanting tomatoes or planting cotton. A summary of pre-tomato tillage operations used in each system is shown in Table 4.

CT Equipment

A few equipment modifications have been made in the CT system. A three-row transplanter sled fitted with 20-inch diameter coulters ahead of each transplanter shoe, residue-slicing disks in front of each sled, and additional press wheels behind the transplanter drive wheels to seal seedlings into the soil were used. A Sukup high-residue corn cultivator (Sheffield, Iowa) was converted to a three-row, 60-inch configuration.

Table 4. Tillage operations used in standard and conservation tillage tomato systems, Five Points, Calif., 1999 – 2005.

Standard tillage	Conservation tillage
• undercut cotton	• undercut cotton
• disk	• transplant tomatoes
• disk	
• rip	
• disk	
• list beds	
• power incorporate beds	
• transplant tomatoes	

and bed-top L-sweep blades were added for tomato bed cultivation. Sidedress fertilizer was applied using Yetter Mfg. (Colchester, Ill.) high-residue liquid or dry fertilizer applicators that had coulters fitted in front of the shanks.

Yields

Processing tomato yields (*cv* Heinz '8892') are shown in Table 5 for 2000 - 2004. CTNO yields matched or exceeded those of either ST system in all five years of this research. Yields of the CTCC system were lower than the other systems in 2000 and were lower than the CTNO in each of the next two years of the project as well. We observed that tomato plants often grow more slowly early in the season in the high-residue CT cover crop mulches. The slower growth is perhaps due to lower measured temperatures above and below the mulch layer. We also observed more surface "trash" entering the harvester in the CT systems. However, virtually all of this mulch was typically removed by the harvester's suction-cleaning mechanism.

Table 5. Tomato yields 2000 – 2004 (tons/acre) from field comparison of standard and conservation tillage production in Five Points, Calif.

	2000	2001	2002	2003	2004
Standard till no cover	58 a	61 b	46 b	42 c	46 bc
Standard till cover crop	53 b	63 a	43 b	45 b	42 c
Conservation till no cover	56 a	64 a	56 a	54 a	52 a
Conservation till cover crop	51 b	61 b	43 b	52 a	48 ab

These results indicate at least the short-term potential to produce tomatoes following cotton with considerably less tillage than is currently done in most production fields. The tillage management approach that has been pursued in this study seeks to reduce primary, intercrop tillage and depends on subsequent, early-season bed "reconditioning" with the transplanter and cultivator operations. By doing this, beds have been left quite rough during the winter and into the spring. This may be a management strategy that today's growers may not be comfortable with because early-season beds are rather degraded and may not be well shaped. In this study, however, we have found that it is possible to establish tomato transplants into these beds, to rebuild beds using the transplanter and cultivator that are both fitted with "ridging wings" or furrowing tools, and to successfully mechanically harvest fruit with this management system. With this approach, early cultivation is needed to recreate furrows and to clean residues out of furrows to enable surface irrigation.

Within this CT tomato system, the largest challenge has been to consistently manage weeds during the entire production season. The strategy we have pursued involves cultivation-generally two to three times per season-and hand weeding. However, because herbicides have not been incorporated into the soil, the CT systems have consistently had many late-season weeds grow in the furrow, and they have not been effectively managed because the tomato plants are by then too big to allow topical herbicide spraying or cultivation. There is thus a need to improve the CT systems, particularly late in the season.

Developing CT Dairy Forage Production Systems

California's dairy industry is a huge contributor to the state's economy. Dairy products have been California's top agricultural commodity for a number of years (CDFA, 2004). They account for more than $5 billion in cash receipts, which is about 17% of the state's overall agricultural output in recent times. California dairies require year-round availability of inexpensive, locally produced forage materials. Common dairy forage production systems consist of winter small grains seeded either individually or in mixes in November and December. These winter forages are then harvested as "green chop" the following March through May. In conventional production systems, fields may be disked a number of times following the harvest of these winter forages, relisted or bedded, and then preirrigated for spring corn planting. Turnaround time between winter small grain forage harvest and spring corn planting routinely takes about two weeks. Spring silage corn is then produced for late-summer harvest. Occasionally, corn or another forage crop such as milo or sorghum sudan, may be double-cropped after an early planted corn crop, with the second crop coming off sometime in early fall. In most current production systems, intercrop tillage and seedbed preparation is done ahead of each successive crop. Such production systems, however, lend themselves quite well to a variety of conservation tillage approaches that have been developed in other production regions, and in recent years, a number of California dairy forage producers have begun experimenting with these reduced- till forage production alternatives.

The primary motivation for CT in dairy forage systems is to save time, labor, and fuel. This is accomplished by reducing primary, intercrop tillage or soil preparation operations such as disking, plowing, chiseling, and ripping to the greatest extent possible while still achieving adequate productivity. In general, the earlier that a crop such as corn is planted, the higher the yield. Corn stunt disease is also less severe in early corn than in later-planted corn. Minimizing or eliminating intercrop tillage can reduce the time between winter forage harvest and corn seeding from two to three weeks under conventional practices, down to seven to 10 days or even less due to reduced time for tillage operations, and less water applied as pre-irrigation.

There are currently three general types of conservation tillage being used in Central Valley dairy forage production fields: complete no-till, strip-till, and a one-pass operation in which several implements such as a light disk and a harrow are pulled in tandem to create seedbed conditions quite similar to conventional tillage. In no-till or zero-till, the only tillage used is soil disturbance in a narrow slot created by coulters or seed openers during planting. The soil surface is thus generally left undisturbed except at the time of planting. In strip-till, coulters cut residues ahead of subsoiling shanks that loosen the soil from a few to as many as 14 inches deep ahead of a planter. A strip-till implement can also be connected to a planter to enable a one-pass planting operation. Finally, strip-till is sometimes referred to as “vertical till” because tillage is done in a vertical fashion in the soil profile, thereby preserving much of the residues on the soil surface. A variety of implements, including a basic disk-harrow and other recently introduced and more specialized “all-in-one” type tillers can also be used to accomplish the reduced-pass approach. This latter CT system reduces the number of overall tillage operations while tilling the surface soil sufficiently to mix residues with the soil, thus providing seedbed conditions relatively comparable to standard tillage procedures. Specific examples of CT that have recently been used in Central Valley dairies are listed in Table 6.

Table 6. Conservation tillage dairy forage production evaluations conducted in the Central Valley, 2002 – 2005.

- no-till corn planted into winter small grain forage
- strip-till corn planted into winter small grain forage
- strip-till corn planted into burned-down alfalfa
- no-till sorghum sudan drilled into corn stubble
- no-till corn planted into corn stubble
- no-till triticale drilled into sorghum sudan
- one-disk corn planted into winter small grain forage
- no-till oats drilled into alfalfa
- no-till wheat drilled into corn stubble

Summary

Conservation tillage production systems have the potential to significantly transform major sectors of California agriculture in the coming years. In their many and varied forms, CT systems eliminate traditional soil preparation operations such as plowing, disking, and ripping, thereby reducing fuel use, production costs, and dust emissions. While soil tillage practices in California have changed little during the past 60 years and estimates of the use of CT in California are currently quite low, projections of UC's CT Workgroup indicate huge and as yet largely unexplored potential for CT in the state. In order for conservation tillage production systems to be realized and sustained in California, however, many fundamental and applied research questions remain to be addressed and resolved.

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LONG-TERM ASSESSMENT OF NITROGEN USE AND LOSS IN IRRIGATED ORGANIC, LOW-INPUT AND CONVENTIONAL CROPPING SYSTEMS

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Abstract

Nitrogen (N) use is compared among organic, low-input, and conventional farming systems in two long-term research experiments: 1989-1998 at the Sustainable Agriculture Farming Systems (SAFS) site, and 1993-2004 at the Long-Term Research in Agricultural Systems (LTRAS) site, both at the University of California, Davis. N balance, storage, and loss were evaluated at each site to assess the efficiency of each system. At both sites, the conventional system had the highest N output, while the organic system had the greatest cumulative N input and N balance. Organic systems at SAFS and LTRAS accumulated 901 kg N ha^{-1} and 685 kg N ha^{-1}, respectively, three to 11 times more N than the low-input and conventional systems. At SAFS, corn and tomato yields were comparable among systems in the four-year, five-crop rotations of tomato, safflower, corn, oats/vetch, and beans. At LTRAS, tomato yields followed similar trends among systems under a two-year, two-crop rotation of tomatoes and corn. However, conventional corn yields were consistently higher than low-input and organic corn yields. Differences in corn yields between the two sites may be attributed to variation in crop rotation, timing of planting, or lack of synchronization between N mineralization and crop N demand.

Key words: agriculture, nitrogen, long-term, organic, California, conservation farming systems

WEED MANAGEMENT ISSUES IN 'CONSERVATION TILLAGE' AND 'REDUCED-RISK PEST MANAGEMENT SYSTEMS'

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Abstract

Tillage has been a major weed-control tool for several decades, and any effort to reduce or eliminate tillage is perceived to increase the likelihood for increased weed populations and species shifts. Thus, weed management issues are often cited as one of the major reasons for growers not readily transitioning to conservation tillage (CT) systems. However, soil quality concerns, environmental issues, rising fuel prices, farm economics, and regulations have led to a renewed interest in CT systems. Similarly, concerns on human and animal health have promoted "reduced-risk pest management" systems in agricultural and non-agricultural areas. The basic tenets of weed management often tend to be ignored and "silver-bullet" approaches seem to be adopted in the quest for these "environmentally friendly" and "reduced-risk" pest management systems. A result of this approach is the rapid increase in herbicide-resistant weeds and selection for difficult-to-control weeds. Weeds need to be recognized as a component of a "bigger system" and a "systems approach" needs to be taken for their management. Proper identification, monitoring, timely interventions, selection and rotation of herbicides and other tactics, prevention of new introductions, and minimizing seed return "remain" as essential components of weed management. Examples will be presented on the status of herbicide-resistant weeds and our experiences in weed management in CT and non-agricultural areas of California.

Key words: weed management, conservation tillage, "reduced-risk" pest management systems, conservation farming systems

A DYNAMIC ECONOMIC ANALYSIS OF SUSTAINABLE FARMING SYSTEMS IN CALIFORNIA PRODUCTION

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Abstract
Short-run budget analyses show that production of tomatoes and corn in California is most profitable using standard tillage (ST), compared to using conservation tillage (CT) and winter leguminous cover crops (WLCC). Valuation of the long-run economics of alternative farming systems in terms of the capital value of soil and ecological resources leads to different results. Conservation tillage increases the soil's water-holding capacity, improving the stock of soil moisture and nitrates for crop production. WLCCs also generate stocks of organic matter and nitrate that have a long-run capital value. Therefore, if long-run profits and ecological benefits are considered, use of CT and WLCCs may increase. Experimental data from field trials is used to calibrate a crop-simulation model, EPIC, that generates a time-series cross-sectional data set. We develop bioeconomic models for each of the farming systems to estimate their long-run profitability and associated ecological benefits. Profit-maximizing farmers may adopt alternative methods in the long run when the capital value of soil resources is included. Finally, when regulatory constraints are imposed, for example to reduce non-point source pollution, results from our bioeconomic models are expected to show that conservation tillage and winter legume cover crops are more sustainable than current standard practices.

Key words: sustainable farming systems, bioeconomic modeling, capital value stocks, ecological benefits, cover crop, conservation farming systems

TRANSFER OF PERCHLORATE FROM DAIRY FEED TO MILK: POSSIBLE EXPOSURE SCENARIOS.

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Abstract

Concern for human exposures to perchlorate has been a subject of intense debate for several years. Adding to this debate are recent discoveries of low levels of perchlorate in milk. Determining the extent to which perchlorate in dietary intake (feed + water) is transferred to milk will aid in managing human exposure. In addition to natural exposure from low concentrations of perchlorate in feed and water, Sixteen lactating dairy cows were ruminally infused with known perchlorate concentrations (0, 0.4, 4.0 and 40 ppm) and perchlorate transfer into the milk was monitored. From these data, a dose-response relationship was established between increasing levels of perchlorate in feed versus its appearance in milk. The concentrations in the milk was directly related to the levels in the feed; however, especially important was the discovery that the efficiency of transfer to the milk diminishes in a regular and predictable pattern as the concentration in the feed increased. Using USDA Food and Nutrition Survey data and USDA Nutritional Information data, potential perchlorate exposures from milk were determined. These overall findings emphasize the need to better understand how perchlorate cycles through the environment and ends up in dairy feed.

Key words: Perchlorate, milk, dairy feed, feed exposure

PERCHLORATE: AN EVALUATION AND PRACTICAL FRAMEWORK FOR STAKEHOLDERS

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Abstract

Perchlorate may be present in soils used for production of garden vegetables and other food crops. This work reviews perchlorate with an emphasis on environmental regulations, food safety, risk management, remediation technologies, socioeconomic implications, and stakeholder solutions. The Environmental Knowledge and Assessment Tool (EKAT) is used in this review to search for available information; meaningful results are further evaluated through a six point framework. Because of the need to limit perchlorate consumption, the uptake of perchlorate into food crops is reviewed as well. Study findings confirm that the regulatory status of perchlorate is undergoing policy determination and that various initiatives are moving forward. Solving complex ecopolitical problems, like those associated with perchlorate, requires a balance of bottom-up (local knowledge) and top-down (centralized incentive) led measures and tools available to stakeholders. Outreach and extension professionals can play an instrumental role in this process. A panel of distinguished researchers, program managers, and policy analysts discussed these issues during the International Conference on The Future of Agriculture: Science Stewardship, and Sustainability.

Key words: perchlorate, plant uptake, soil, food safety, stakeholders

Introduction

Although various forms of perchlorate (ClO_4^-) have been utilized as (feedstock) products for decades, only in recent years has the compound received widespread notoriety. With growing public attention and concern, this chemical continues to present challenges in the scientific and policy-making spheres of society. Beyond the important realms of post-industrial cleanup and public water supply, the perchlorate controversy has also emerged as an agricultural and consumer topic for the public to examine.

Information, including access and interpretation, is a powerful force that drives public perception and prioritization with many current issues and events. Consequently, an empowered citizenship requires useful and effective tools with which to analyze and understand such perplexing topics as perchlorate, that often have social and economic dimensions above and beyond established technoscientific principles.

Given the existing complexities and uncertainties related to perchlorate, a streamlined review of publicly available literature was performed. Of particular significance was the simple and pragmatic framework employed during this study. Initially, a software tool (Environmental Knowledge and Assessment Tool [EKAT]) was used for chemical and regulatory screening and then a basic six-point method of inquiry was applied to characterize germane information. A technical session was convened and utilized this information in conjunction with viewpoints by subject matter experts and conference participants.

Approach

The first step of study involved environmental exploration with the user-friendly EKAT, a Web-based research, project management, and decision-support tool created to identify, examine, and evaluate environmental and safety-related issues for products and systems. The program presents information on technical and regulatory requirements and serves as a preliminary environmental screening tool for potential issues of concern. EKAT also serves as a resource center with links to other references, tools, and databases to assist in efforts designed to minimize unintentional safety and environmental effects by using publicly available environmental information and software applications (M2 et al., 2006).

Initial EKAT queries determined that perchlorate was not regulated by any major federal law, nor was it contained on any of the carcinogen data lists managed by the system. Additionally, an EKAT solvent screening step indicated that perchlorate was not listed as a toxic air pollutant or regulated hazardous waste for any of the states for which data are maintained. However, considerable background information and many references were available in the EKAT Information Resources database. The information was compiled, along with findings from several other published articles and studies, for critical review.

To frame the review, the six-point approach (based on standard *What*, *When*, *Where*, *Who, Why*, and *How*) incorporated vital questions for analysis. Mindful integration of essential perspectives (e.g., technical, social, and economic) was used for basic scoping. This simple hexa-system of examination is often used to gauge completeness and credibility in many endeavors, ranging from journalism to criminal investigations to internet information. Nobel Prize Laureate Rudyard Kipling captured the spirit of this approach and its utility well in his writings, noting that "I keep six honest serving-men: (They taught me all I knew)…I send them over land and sea, I send them east and west; But after they have worked for me, I give them all a rest…" (Kipling, 1902). Accordingly, the following interrogatives were used to define fundamental concepts and outline the issue for understanding.

- *What* exactly is perchlorate?
- *When* did perchorate become a concern?
- *Where* did perchlorate come from? *Where* is it now?
- *Who* is at risk?
- *Why* is perchlorate receiving so much attention?
- *How* can we address the challenge?

Representatives from the U.S. Environmental Protection Agency (Kevin Mayer), U.S. Department of Agriculture (Cliff Rice), California Water Quality Control Board (Robert Holub), University of Arizona (Charles Sanchez), and Kansas State University (Oral Saulters), participated in an interactive forum to discuss ideas and issues surrounding perchlorate during the conference. The format and content of the session leveraged this practical framework. Individual presentations and group conversations with the audience (which stressed current and future possibilities in research, policy, and practice) strived to advance collective understanding.

Evaluation

What exactly is perchlorate?

Perchlorate is a negatively charged ion (anion) comprised of one chlorine atom bonded to four oxygen atoms (ClO_4^-). It has natural origins, and is found as perchloric acid ($HClO_4$), or commonly with positively charged counter-ions (cations) such as ammonium (NH_4^+), sodium (Na^+), potassium (K^+), and magnesium (Mg^{2+}), resulting in the formation of salt compounds (see Table 1). Although there is some variation between the perchlorate forms, generally, the high solubility and mobility in water, along with stability under ambient conditions, present a persistent contaminant challenge in surface and groundwater systems. The anion does not readily hydrolyze under environmental Eh and pH conditions (Mirecki et al., 2006). While the chemical does not readily degrade in surface soils, it has been demonstrated to be biodegradable by specific microorganisms.

Table 1. Descriptive properties of various perchlorate compounds

Properties	Ammonium Perchlorate	Magnesium Perchlorate	Potassium Perchlorate	Sodium Perchlorate	Perchloric Acid
CAS; DOT/UN Numbers	7790-98-9; UN 1442	10034-81-8; UN 1475	7778-74-7; UN 1489	7601-89-0; UN 1502	7601-90-3; UN 1873/1802
Molecular Formula	NH_4ClO_4	$Mg(ClO_4)_2$	$KClO_4$	$NaClO_4$	$HClO_4$
Molecular Weight	117.49	223.20	138.55	122.44	100.47
Color/Form	White orthorhombic crystals	White, granular, or flaky powder	Colorless or white crystals	White orthorhombic crystals	Colorless, oily liquid
Taste/Odor	Odorless	Odorless	Slightly salty	Odorless	Pungent odor
Melting Point	270ºC	250ºC	525ºC	480ºC	-112ºC
Density/SG	1.95	2.2	2.52	2.02	1.77
Solubility @ 25ºC (g/l water)	200	993	15	2090	Miscible
Stability/Shelf Life	Unstable	Stable under ordinary conditions	Expiration date of 6mo	Stable for at least 9 mo	Unstable, volatile, may explode
Major Uses	Chemistry, etching/engraving agent, smokeless rocket and jet propellant	Regenerable drying agent for gases, oxidizing agent	Explosives, pyrotechnics, photography, analytical chemistry	Jet fuel, analytical reagent, radiation protection, explosives, intermediate	Analytical chemistry, explosives, plating, titration, catalyst

Based on National Library of Medicine, Toxicology Data Network results

When did perchorate become a concern?

The current widespread concern with perchlorate was first triggered in 1997 because of health concerns. Previously, as early as 1985, perchlorate had been discovered at Superfund sites in California, however, because of limitations in validated analytical methods and unknowns with possible health effects, other contaminants were given higher priority.

With the advances in detection technology which allowed perchlorate to be measured in water at concentrations as low as 4 parts per billion (ppb), perchlorate soon emerged as a national issue (NRC, 2005).

Where did perchlorate come from? Where is it now?

Perchlorate has been determined to be both naturally occurring and chemically synthesized. For many years Chilean nitrate (~0.1% perchlorate) was thought to be the only natural source of the compound (Dasgupta et al., 2005). The mineralogical ore deposits in Chile have been mined and imported into the United States since the 1800s and used for fertilizer, gunpowder, and industrial feedstock. Chilean nitrate fertilizer was primarily used in the U.S. before the 1960s. However, recent studies have identified other possible natural sources of the compound. These sources include atmospheric deposition mechanisms derived from natural chloride compounds (marine and/or terrestrial) reacting with atmospheric ozone to create perchlorate in processes analogous to nitrate formation. The USGS and others are evaluating the nature and extent of these natural deposits, especially in arid environments (Rajagopalan et al., 2006).

Anthropogenic sources of perchlorate include manufacturing facilities with production processes operating in the U.S. since the early 1900s. Percholarte's use and production increased in association with World War II due to its effective properties as an oxidizer with many strategic applications. A vast majority of the industrial perchlorate produced is for ammonium perchlorate used in the defense and aerospace industries as an oxidizing agent for solid propellant rockets and missiles. Additionally, many military weapons systems contain varying amounts of perchlorate. The manufacturing, operations, and disposal of these munitions systems have resulted in releases to the environment. Other noteworthy contaminant sources include commercial explosives, fireworks/flares, industrial, agricultural, and medical products, wastewater treatment, landfills, etc (ITRC, 2005).

Since 1997, perchlorate has been identified in a number of states across the country, with several detections in California, Texas, New Jersey, and Massachusetts. Initial contamination was found in water resources, with an emphasis on drinking water supplies; however, by 2004, over 150 sites in 35 states had measured soil and water impacts (US EPA, 2004). An illustration of the pollutant's perplexing geographical reach was the multi-state mystery in the southwestern U.S. Ultimately, perchlorate discoveries in southern California revealed contamination stretching back up through the California-Arizona border and into Nevada via the lower Colorado River. The provenance was determined to be a defense contractor facility located just outside Las Vegas that had manufactured perchlorate for nearly half a century. With roughly 15 million people using the lower Colorado as a drinking water source and perchlorate levels of 4-16 ppb in the river, the interstate plume presents unique geopolitical, engineering, economic, and legal predicaments (Hogue, 2003). These issues go far beyond the region with connection to national and international distribution of irrigated food and feed.

Soil and Vegetation

While the physiochemical properties of perchlorate are well established and much focus has been placed on its impact on water resources, there is a paucity of information regarding its distribution in soils. Generally, perchlorate does not bind significantly to soil particles (increased potential with low pH soils and higher anion exchange capacity). Fate and transport are closely linked with the soil and subsurface moisture content. Research by the Corps of Engineers shows that ClO_4^- moves through soils with very little sorption; with neither soil type nor oxygen state having substantial effects (Dalton et al., 2004). Perchlorate in the dissolved phase can be very mobile; however, its presence and migration in the solid phase (as from secondary explosives) can vary with soil heterogeneity and partitioning factors.

Capillary forces in the unsaturated zone may hold perchlorate in solution. In arid regions this can lead to accumulation as the water evaporates. This is how the Chilean nitrate deposits were formed. Hydrogeologic findings in the southwestern U.S. have noted higher perchlorate concentrations in areas with shallow groundwater, lower saturated thicknesses, and irrigated land use (Rajagopalan et al., 2006). Additionally, perchlorate in soil moisture can be sequestered and extracted by plants through the root system. Several studies have demonstrated the ability of plants to accumulate perchlorate in tissues and leaves; this process has also been investigated as a potential remediation method.

For vegetation, the presence of perchlorate, in supporting soils and water, presents an interesting mix of possibilities for uptake, distribution, transpiration, and exudation dynamics. Mass balance research with tobacco plants has illustrated that perchlorate can be taken up by the root system, transported up the stem via the xylem, and accumulated in the vacuoles of leaves and stems (Sundberg et al., 2003). Studies with citrus (lemon, grapefruit, and orange) in the southwestern U.S. indicate that perchlorate can accumulate, with concentrations highest in the leaves and fruit (branches, trunk, and roots contained much less of the chemical) (Sanchez et al., 2006). Experiments with various forage and edible crops have also found that concentrations in the leaves were higher than those in the fruit, seeds, and pods of select plants. Results also determined that perchlorate concentrations were higher in plants grown in soil than those grown in sand (Jackson et al., 2005). Given the variations between plant species, measured bioconcentration factors (ratio of plant [fresh weight] concentrations to groundwater concentrations) have verified that various forms of vegetation can and do accumulate perchlorate and can serve as media for ecological transfer and exposure. Leafy vegetables, including lettuce among others, have been noted as being relatively high accumulators of perchlorate (Hutchinson, ND).

Moreover, findings suggest that there may be threshold concentrations and that evapotranspiration can be a driving variable in predicting accumulation (Yu et al., 2003; Tan et al., 2006). Factors such as pre-exposure, external nutrients, nitrate concentrations, and availability of organic substrate strongly influence uptake and degradation (Jackson et al., 2004). All of the studies reviewed, appear to confirm the potential for exposure through routes other than drinking water.

Food and Consumer Connections

Another important development has been the discovery of perchlorate in the food supply. It is suspected to have entered the food web through soil and/or irrigation water containing the chemical. Detections in produce, milk, and other foods have triggered additional investigations and strong public concern (EWG, 2006). Studies have been initiated by the U.S. Food and Drug Administration to ascertain the extent of perchlorate occurrences in various food sources. The FDA developed a rapid and sensitive analytical method to detect the perchlorate ion in select foods (US FDA, 2004). Initial exploratory studies completed in 2004 for lettuce, milk, and bottled water, revealed various levels (see Table 2). Findings from further studies by the FDA on milk, produce (i.e., tomatoes, carrots, cantaloupe, and spinach), juices, baby food/formula, grain products, and aquaculture raised seafood have not been publicly released (Hogue, 2005).

Table 2. Summary of U.S. FDA results for exploratory survey of select foods

Food Product	Number of Samples	Median Perchlorate Levels Detected (ppb)
Milk	104	5.76
Bottled Water	51	NQ*
Lettuce iceberg, green leaf, red leaf, and romaine	128	7.76, 10.7, 11.6, and 11.9

*49 samples were non-quantifiable, and two spring water samples of 0.45 and 0.56 ppb (US FDA, 2004)

Many other research groups are also working to collect data on food and consumer-related sources. For example, the USDA is evaluating perchlorate transfer mechanisms in plants and animals (e.g., perchlorate consumption and effects on cows) (Kaplan, 2005). An investigation led by the University of Arizona involving leafy vegetable surveys in North America (outside the lower Colorado River region), indicates that 16% of conventionally grown produce and 32% of organically grown produce sampled, contained measurable levels of perchlorate. Additionally this same study compared the relative concentrations of nitrate and perchlorate via the perchlorate equivalent concentration (PEC), thus demonstrating the importance of accounting for mixtures of iodine uptake inhibitors in calculating risk more comprehensively (Sanchez et al., 2005).

Studies of tobacco plants showed the presence of perchlorate not only in the leaves of recently exposed plants, but also in samples of commercially purchased tobacco products (chewing tobacco, cigars, and cigarettes), thus exhibiting surprising persistence through the aging and curing processes (Sundberg et al., 2003). In separate studies, perchlorate was also detected in such disparate products as: over-the-counter vitamins, seaweed, soil amendments, and human urine samples, thus adding to the growing list of unexpected sources (Renner, 2006).

A recent study of a new analytical approach that was tested through measuring perchlorate concentrations in food and beverage products (e.g., fruits, wines, and beers) from international sources, identified notable levels (Aribi et al., 2006). The new method, ion chromatography coupled with tandem mass spectrometry (IC-ESI-MS/MS), utilized for the survey is capable of measuring down to low parts-per-trillion limits. With over 350 samples collected and analyzed, all but four contained measurable levels of perchlorate. Some of the higher values were detected in: water samples from Las Vegas (2.9 ppb, tap) and Portugal (5.1 ppb, bottled); produce samples (median values) from Guatemala (169.7 ppb), Costa Rica (76.34 ppb), Mexico (39.9 ppb), and Chile (23.1 ppb); wine samples (median values) from Chile (15.5 ppb) and Spain (4.3 ppb); and beer samples from France (10.7 ppb) and Chile (6.7 ppb). Other noteworthy findings were 1) ion exchange filters effectively removed perchlorate from water and 2) perchlorate can persist in food even after being cooked.

Sunflower State

From the global to the local, examples of the complicated issues surrounding perchlorate exist in the center of the U.S. and serve as a useful, albeit limited microcosm. Perchlorate contamination associated with the manufacture, storage, and use of explosives presents elaborate challenges at three different Kansas sites. The first is a former manufacturer of slurry explosives in the southeastern part of the state. Past practices have resulted in surface and groundwater impacts. Flora and fauna in the area have also been adversely affected. Consequently, based on the levels detected in the water and fish tissues, in 2003 state regulatory agencies began issuing annual consumption advisories, for all forms of aquatic life because of perchlorate levels (KDHE, 2005).

The second case involves an active Army installation which has been operating as a training and education center since the 19th century. As a National Priorities List (Superfund) site, it is contending with many investigation requirements, including the remnants of historic munitions exercises. Open burn/open detonation (OB/OD) activities conducted on the base have resulted in groundwater (and associated spring) contamination ranging from 22 to 70 ppb. Although there is no active remediation planned, based on limited risk to human health, the installation continues to monitor ground and surface water to ensure the pollutant does not migrate beyond the site boundary (US DoD, ND).

The third instructive Kansas example is a manufacturing facility that produced a substitute for black powder (for muzzle loading fire arms). State authorities discovered widespread perchlorate contamination beginning in 1998. In addition to the immense groundwater plume (estimated to cover nearly 25 square miles), agricultural products and soils were impacted. Potential concerns with garden vegetables resulted in agency recommendations to avoid using the water (for irrigation) and consuming the produce, along with suggestions to relocate gardens due to concerns with perchlorate accumulation in soils (KDHE, ND).

While these three individual cases are only briefly discussed here, they convey some sense of the technical and administrative concerns surrounding hitherto acceptable procedures in perchlorate production and management, and the subsequent contamination generated from those practices. Also, these synopses of perchlorate challenges in rural areas of a Midwestern state (rather than more publicized concerns in populous U.S. coastal zones), provide a valuable reference point and illustrate how confounding factors involving diverse interests (e.g., industrial, military, wildlife, agricultural, etc) can underlay decision-making and evince the need for innovative joint strategies.

Who is at risk?

Recent studies reveal that more than 11 million people have perchlorate above 4 ppb, in their drinking water supplies. Perchlorate has not been linked to cancer in humans; the health concern with perchlorate is its capacity to interfere with the uptake of iodide by the thyroid gland. Because iodide is essential to the production of thyroid hormones, which are critical for growth and development in fetuses, infants, and young children, reductions can lead to neurodevelopmental deficits. Additionally, thyroid hormones assist in the regulation of body metabolism in adults (NRC, 2005).

Historically, perchlorate has been used medicinally to diagnose and treat metabolic disorders such as hyperthyroidism, but it is rarely used as such today. There is evidence that high exposures to perchlorate may result in thyroid gland tumors. The most sensitive human populations are pregnant women, fetuses, and young children, along with those who have compromised thyroid function and iodide deficiencies.

Because most of the health studies to date have emphasized the human-related effects of perchorate, data on potential ecological impacts are limited. Some field studies have found that perchlorate does not generally bioconcentrate in small mammals; and laboratory studies of terrestrial and aquatic organisms show varying endpoint effects (including endocrine disruption) at different levels. Overall, more research and site-specific field data are needed to ascertain meaningful ecosystem conclusions (Kendall, 2003).

Why is perchlorate receiving so much attention?

There are many diverse stakeholders interested in the future of perchlorate (including its regulatory status). Along with the potential sources and related environmental and food impacts briefly noted in earlier sections, many private, public, tribal, and nongovernmental organizations are involved in activities to gather information, clarify uncertainties, and devise interim and long-term solutions. For example, the Interagency Working Group of the Interagency Perchlorate Steering Committee established in 1998, includes: DoD, EPA, NASA, DOE, FDA, USDA, ATSDR, DOI, OMB, CEQ, and the Office of Science and Technology Policy (US DoD, ND). Also, industry groups, manufacturers, and users of perchlorate, have established partnerships and organizations, which fund perchlorate studies and disseminate information.

Perchlorate is currently not regulated on a federal basis, however, since 1999 the USEPA has been monitoring for the compound in public drinking water systems via the Safe Drinking Water Act's Unregulated Contaminant Monitoring Rule (UCMR) program. Plans for continuing the next phase of the program and increasing its scope, could lead to further detections. The DoD has been particularly concerned about regulation and direction, with more than 350 types of munitions containing perchlorate and two ranges shut down because of contamination (Hogue, 2005). Due to continued questions, uncertainties, and differences in perspective, the National Research Council of the National Academy of Sciences (NAS) was engaged to review available health data, including the USEPA 2002 draft risk assessment.

Based on the conclusions and recommendations submitted by the NAS in 2005, the USEPA established a human reference dose of 0.0007 milligrams/kilogram/day (mg/kg/D). The reference dose, which is an estimate of a daily exposure level not expected to cause adverse health effects in humans, was used to derive a drinking water equivalent level (DWEL) of 24.5 ppb and supersedes the 1999 interim range set by the USEPA of 4 to 18 ppb. It should be noted that the DWEL calculation assumes that all contaminant exposure comes from drinking water (does not consider contribution of other routes such as food products) and serves as a preliminary target goal, rather than a final enforceable standard. Utilization of this value has drawn strong criticism from several groups. To date, no national Maximum Contaminant Level (MCL) has been established by USEPA; however, several states are considering their own standards which further intensify decision-making and debate. Massachusetts and California have proposed limits of 2 ppb and 6 ppb, respectively (Journal AWWA, 2006).

Significant economic ramifications are expected due to the extensive presence and possible mitigation necessary to protect human health and the environment. This is a matter of especial importance to: potentially responsible parties, site owners/operators, remediation technology companies, municipalities, and consumers. Water resources tainted with perchlorate not only present quality concerns, but can restrict quantity, thus forcing water utilities to make difficult decisions, including litigation and increased water rates (Buehrer, 2005). In California alone, the estimated cost for public water systems to comply with potential regulatory standards (i.e., MCLs) could be in excess of one billion dollars over the next 20 years (Kennedy, 2004). These costs do not include impacts to other sources such as private wells, agricultural wells, and the Colorado River. The DoD has spent nearly $60 million dollars on perchlorate-related activities (e.g., remediation, prevention, and studies) (US DoD, ND). With expanding concerns in the food and consumer product sectors, additional cost-factors could be involved and thereby exacerbate controversies considerably.

How can we address the challenge?

Although it can be difficult for the public to draw coherent conclusions based on media headlines and sound bytes, especially regarding agriculture and food dimensions of the perchlorate challenge, information synthesis and social learning will be required. Recent progress with new technologies involving analytical methods and cleanup strategies appears promising. With innovations in analytical procedures, and increased sensitivities/selectivities, previously unexamined areas (locations and matrices) of environmental study with perchlorate are emerging. Although only one method (Method 314.0 Ion Chromatography) is currently approved by USEPA, method validation studies are underway. As new methods become available and are approved, capabilities and options will increase. In addition to the laboratory methods, new field and forensic techniques are also moving forward.

Proven and commercially-available in situ and ex situ technologies for addressing perchlorate contamination in water, including ion exchange, biotreatment, activated carbon, and chemical reduction; and more novel approaches with phytoremediation (plant based), membranes, and electrochemical reactions, provide optimism as part of a developing remediation portfolio. Currently, ion exchange and biotreatment are the most widely used, and through process optimization and cost analysis, efficiencies are improving (Zerovnik and Longville, 2006).

The incorporation of engineered biological systems into stand-alone or treatment train approaches is very intriguing. Of special note is the emerging field of phytoremediation technology which involves the use of plants to remove contaminants from soil and water. Harnessing this natural capability, which on one hand presents challenges for agriculture, proves beneficial for cleanup objectives. Several studies have documented that designated plants (e.g., tobacco, lettuce, willow trees, poplar trees, etc.) and associated microbes (*Dechloromonas*) in the root zone are capable of effectively uptaking, accumulating, and/or degrading perchlorate under certain conditions (Mirecki et al., 2006; Yifru and Nzengung, 2005; Shrout et al., 2006). Research is underway to better understand and enhance the specific underlying mechanisms.

Much of the uncertainty with perchlorate, including delineating its extent and pervasiveness, current and future regulations, risks to human health and ecosystems, and practical resolution, can be rectified only through cooperative partnerships. As for proactive changes toward pollution prevention and product substitution, environmental management systems (EMS) and best management practices (BMPs) are being adopted in several areas while programs such as the Strategic Environmental Research and Development Program and non-lethal weapons initiatives are exploring viable alternatives. Perchlorate is also being recovered and recycled from demilitarized munitions (Hogue, 2005). Although crucial, technoscientific innovations are only part of the answer. Complementary military, political, and socioeconomic strategies are also critical for achieving long-term goals. Collaboration between various groups will be essential for shaping policy and stimulating the necessary integrated solutions.

Conclusion

The regulatory status of perchlorate is still under review, nonetheless, various targeted and robust initiatives are moving forward. Recent reports note that the sources and extent of perchlorate contamination are more widespread than initially suspected. Most of the focus to date has been on groundwater related concerns; however, the discovery of perchlorate in various foods, beverages, and other products has raised new questions about prevalence, risk, and mitigation priorities. More data collection is necessary to address uncertainties and needs before conclusive determinations can be made (Newman, 2006).

The mainstream attention, including potential impacts and costs, has elicited concerted interest from various public and private groups. As federal, state, local, and tribal governments pursue strategic planning and policy formulation goals, affected communities would benefit from open forums on perchlorate, thus advancing opportunities for awareness and understanding. To solve these types of demanding ecopolitical problems will require a balance of bottom-up (local knowledge/ownership and empowerment) and top-down (centralized/institutional incentive) led measures and tools, available to stakeholders. Outreach and extension professionals should play an instrumental role in this process.

In brief, the approach followed in this simple evaluation was efficacious in identifying, dissecting, and summarizing broadly based perchlorate information and resources. The basic steps and succinct descriptions of key topics utilized in this review may be useful to different stakeholders for establishing a common basis from which general fact-finding, data gap assessments, and follow-up activities can be launched. Use of EKAT and the six-point strategy can be easily incorporated into individual and/or community-driven information searches and guide public dialogues on complex environmental topics. This method assisted in steering a perchlorate panel discussion, as part of the milestone International Conference on The Future of Agriculture: Science, Stewardship, and Sustainability, August 2006.

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POTENTIAL PERCHLORATE EXPOSURE FROM FOOD AND FEED CROPS IRRIGATED WITH COLORADO RIVER WATER

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Abstract
The Colorado River is contaminated with low levels of perchlorate derived from aerospace and defense-related fuel industries once located near the Las Vegas wash. At sufficiently high dosages, perchlorate can disrupt thyroid function by inhibiting uptake of iodide. We have found trace levels of perchlorate in a number of food and forage crops grown in the lower Colorado River region. Potential perchlorate exposures from the consumption of individual food crops produced with Colorado River water are low relative to the reference dose (RfD) recognized as safe by the National Academy of Sciences. However, because we observed some level of exposure with each food crop evaluated, additional work was needed to evaluate hypothetical cumulative exposure from all food and forage crops produced in the lower Colorado River region. Results indicate that relative to the RfD, there is a potential for cumulative exposure to become a regulatory issue with children but not adults. The iodide-uptake inhibition potential of perchlorate relative to other natural goitrogens in food crops will also be discussed.

Key words: perchlorate, agriculture, food, Colorado River

AGRICULTURALLY RELATED WATER QUALITY PROBLEMS IN THE SAN JOAQUIN RIVER

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Abstract

The California Central Valley is a highly productive irrigated agricultural area. The San Joaquin River (SJR) in the Central Valley has 12 violations of water quality objectives (WQOs) (standards) that have caused the Central Valley Regional Water Quality Control Board to develop total maximum daily loads (TMDLs) to control the WQO violations. Nine of the 12 WQO violations are related to discharges/runoff from irrigated agricultural lands. The WQO violations are due to selenium, boron, salinity, oxygen demand (due to algae that develop on nutrients), organophosphorus pesticides, organochlorine "legacy" pesticides, fecal coliforms, and toxicity of unknown cause. In addition, several currently unregulated water quality impairments in the SJR could lead to Clean Water Act section 303(d) listings and TMDLs. Potential future WQO violations include nutrients that lead to excessive aquatic weed growth, water supply tastes and odors, and violation of pH and dissolved oxygen WQOs; total organic carbon; herbicides that are toxic to algae; excessive turbidity; and aquatic sediment toxicity due to pyrethroid-based pesticides. This paper reviews issues that will need to be addressed in meeting TMDL requirements. Irrigated agriculture in the SJR watershed will likely change significantly as a result of complying with TMDL discharge limits.

Key words: San Joaquin River, TMDL, agriculture, water quality impacts

Introduction

Upstream of Friant Dam/Millerton Lake near Fresno, California (see Figure 1), the San Joaquin River (SJR) is of high-quality water, consisting primarily of rainfall and snowmelt from the Sierra Nevada Mountains. Downstream of Friant Dam, the water quality of the San Joaquin River is highly impacted by agricultural and municipal discharges and storm water runoff and by water diversions for irrigated agricultural and municipal use. The federal Clean Water Act (CWA) requires that the Central Valley Regional Water Quality Control Board (CVRWQCB) list waterbodies that have violations of the applicable water quality standards (objectives) (WQOs) as Clean Water Act Section 303(d) "impaired." This listing requires that the CVRWQCB develop a total maximum daily load (TMDL) to control the sources of the chemicals/conditions that cause the WQO violations. Table 1 lists current, pending, and potential future 303(d) listings of water quality impairments and TMDLs in the SJR and in the Delta, which is impacted by SJR-watershed-derived constituents.

This paper presents a summary of the water quality issues associated with each of the existing, pending, and potential future TMDLs for the SJR. It is based on a comprehensive report on these issues (Lee and Jones-Lee, 2006). This report is available at http://www.members.aol.com/annejlee/sjr-WQIssues.pdf. Because of limitations on length of this paper, references to CVRWQCB documents that provide additional information on the TMDLs are not included. They are, however, available in the Lee and Jones-Lee report, through Internet links to the CVRWQCB Web site.

Table 1. San Joaquin River Watershed TMDLs.

Current (Active)
- Selenium
- Salinity at Vernalis, total dissolved solids (TDS), electrical conductivity (EC)
- Boron
- Organophosphorus (OP) pesticides (diazinon, chlorpyrifos)
- Oxygen-demanding substances (BOD/algae, ammonia, organic N)

Pending (to be Developed)
- Organochlorine "legacy" pesticides (DDT, chlordane, dieldrin, toxaphene, etc.)
- PCBs
- Dioxins/furans
- Mercury
    - Sulfate (bioaccumulation of mercury)
- Pathogen-indicator organisms, *E. coli,* fecal coliforms
- Toxicity of unknown cause
- Salinity upstream of Vernalis

Potential Future (to be evaluated)
- Nutrients, excessive fertilization (nitrogen and phosphorus vompounds)
    - high pH, low DO caused by excessive fertilization (photosynthesis/respiration)
- Alternative pesticides to OP pesticides including the pyrethroid-based pesticides that are causing water column and sediment toxicity
- PBDEs
- Total organic carbon, and other chemicals such as bromide that develop into disinfection by-products (trihalomethanes) in treated domestic water supplies
- Excessive sediment, erosion, turbidity
- Herbicides (toxicity to algae)
- Aquatic sediment toxicity (pesticides, nutrients/algae/sediment ammonia, heavy metals, PAHs, and other chemicals)
- Unrecognized Pollutants
    - pharmaceuticals and other unregulated chemicals discharged by confined animal facilities (dairies, feedlots, etc.) and domestic wastewaters

Selenium

The finding of malformed waterfowl in the Kesterson area, which was attributed to excessive selenium derived from irrigated agriculture in the grasslands area (located in the mud and salt slough watersheds – see Figure 1) associated with leaching of naturally occurring selenium in the soils, caused the CVRWQCB to develop a TMDL to limit the concentrations of selenium discharged from this area. This is a phased TMDL, where in 2009, additional restrictions on grasslands area selenium discharges will be implemented. The control of selenium to meet the 2009 TMDL requirements will likely significantly affect discharges of other constituents from the grasslands area, such as salts, nutrients, etc., and the amount of water discharged from this area that ultimately reaches the SJR. There is also concern that the current CVRWQCB water quality objective for selenium is not protective of some fish, such as sturgeon, in the delta.

Salinity and Boron

The SJR and the south delta have been found to contain sufficient concentrations of salinity (total salts) to be adverse to some irrigated agriculture. There is also the potential for boron concentrations in the SJR to be adverse to some irrigated agriculture. The boron is derived from leaching from the soils in the grasslands area. The salinity is derived from irrigated agricultural evapotranspiration and soil leaching. The excessive concentrations of boron and salinity have caused the CVRWQCB to develop a TMDL to control salinity and boron concentrations in the SJR at Vernalis. The State Water Resources Control Board (SWRCB) has required that the CVRWQCB develop more restrictive allowed-salinity concentrations in the SJR upstream of Vernalis. The CVRWQCB is in the process of developing this objective. The management of salinity discharges to the SJR, especially associated with meeting the potential projected upstream salinity WQO, could significantly impact the discharges of other pollutants and the amount of water that enters the SJR from mud and salt sloughs.

OP Pesticides

OP pesticides and other pesticides (such as pyrethroid-based pesticides) used in urban and agricultural areas in the SJR watershed and delta are causing aquatic life toxicity in the state's waters. This toxicity is a violation of the CVRWQCB Basin Plan WQO. The

CVRWQCB has adopted a TMDL for control of OP pesticide discharges in the SJR watershed that cause violations of the OP pesticide water quality objective in the mainstem of the SJR. There are significant deficiencies in the approach that the CVRWQCB is following in attempting to develop aquatic life toxicity control programs in the SJR watershed. These include inadequate control of OP and other pesticide discharges from agricultural and urban areas in the SJR watershed, and inadequate monitoring of compliance with the recently adopted TMDL for OP pesticides in the mainstem of the SJR. At this time, inadequate requirements have been adopted by the CVRWQCB for sediment toxicity testing associated with the National Pollutant Discharge Elimination System (NPDES) permitted urban storm water discharges.

Oxygen-Demanding Substances

Nutrient discharges (nitrogen and phosphorus), primarily from irrigated agricultural tailwater and subsurface drain water discharges, cause the SJR upstream of the Stockton deep-water ship channel (DWSC) to contain large amounts of planktonic algae. The planktonic algae do not cause low DO problems in the SJR because of its shallowness and flow characteristics. However, upon entering the DWSC at the Port of Stockton, planktonic algae in the SJR die, decompose, and exert a significant oxygen demand. This oxygen demand causes DO WQO violations in the DWSC. The low DO problem in the DWSC near the Port of Stockton is caused by the existence of the DWSC, water diversions upstream of the DWSC, and oxygen demand loads that develop on nutrients provided to the SJR upstream of Vernalis, as well as the discharge of ammonia to the SJR by the city of Stockton's domestic wastewater treatment plant. Additional information on the low DO problem in the DWSC is provided by Lee and Jones-Lee (2003, 2004a).

The CVRWQCB has adopted a TMDL, which requires that those responsible for causing or contributing to the low DO problem in the DWSC develop approaches to eliminate DO WQO violations. This TMDL allows responsible parties for the low DO problem (urban and agricultural interests) until 2009 to develop information that can be used to formulate a final TMDL to control the SJR DWSC DO WQO violations. Lee and Jones-Lee (2006) discuss a number of significant problems with the current CVRWQCB and

California Federal Bay-Delta Program (CALFED) approach. These problems need to be addressed now so that the information will be available in 2009 to formulate the final TMDL.

Organochlorine "Legacy" Pesticides

The organochlorine-based pesticides (OCls) such as DDT, dieldrin, toxaphene, etc., were widely used in the Central Valley on agricultural land. Many of these pesticides are highly persistent in soils and aquatic sediments. They tend to bioaccumulate in certain types of fish that are used as human food. Because of their potential to cause cancer in people, these pesticides were banned a number of years ago from further use in the U.S. However, certain types of fish (such as catfish and bass) taken from Central Valley waterbodies contain excessive organochlorine "legacy" pesticides compared to concentrations that are believed to be adverse to human health. This has caused the CVRWQCB to list the SJR as 303(d) impaired because of excessive bioaccumulation of OCls. The legacy pesticides are still being found in storm water runoff from some agricultural lands in the SJR watershed at sufficient concentrations to accumulate to excessive levels in edible fish. Lee and Jones-Lee (2002a) have reviewed the information on excessive bioaccumulation of organochlorine pesticides and PCBs in Central Valley waterbody fish.

While this problem has been well established, based on fish tissue monitoring that has occurred over the past 20 years, no work has been done by the CVRWQCB to begin to develop TMDLs to control the excessive bioaccumulation of OCls in edible fish. This situation is the result of the CVRWQCB and the funding agencies, such as CALFED, placing a low priority on beginning to address this excessive bioaccumulation problem. Because of the importance of this problem as a human health threat, especially to those who use large amounts of Central Valley fish as a necessary part of their diet, a higher priority should be given to funding the necessary studies to define current sources of OCls that are leading to the bioaccumulation of OCl residues in edible fish. This is an environmental justice issue, since some minorities and economically disadvantaged individuals rely heavily on SJR fish as a source of food.

PCBs

Fish taken from some parts of the SJR and parts of the delta influenced by the SJR have been found to contain excessive concentrations of polychlorinated biphenyls (PCBs).

PCBs are organochlorine chemicals (non-pesticides) that were used in industrial processes and electrical transformers. While PCBs in aquatic systems are typically derived from industrial/commercial sources, there is a potential for some agricultural activities to be a source. Bioaccumulation of these chemicals in edible fish is of concern, since PCBs are suspected to be human carcinogens. PCBs, like the other OCls, have been listed for a TMDL to control the excessive bioaccumulation, but work on this problem has not received funding from the CVRWQCB or CALFED to enable the initiation of the studies needed to begin to develop the TMDL. This is another environmental justice issue that needs to be addressed.

Dioxins/Furans

Fish taken from the SJR DWSC near the Port of Stockton have been found to contain excessive concentrations of dioxins/furans. Consumption of fish containing dioxins/furans is a significant threat to human health. This situation has caused the U.S. EPA to list the SJR DWSC near the Port of Stockton on the 303(d) list of impaired waterbodies, which requires a TMDL to be developed to control the excessive bioaccumulation. Dioxins/furans present in the fish taken from this area are derived from the McCormick & Baxter former wood-treating operation. This has led to the situation of the area being designated as a national Superfund site, where the U.S. EPA is the lead agency for site investigation and remediation.

Sediments of Old Mormon Slough, which is part of the McCormick & Baxter Superfund site, contain elevated concentrations of dioxins/furans. Rather than removing the Old Mormon Slough sediments, the U.S. EPA has chosen to cover these sediments with clean sand, in an attempt to prevent further bioaccumulation of dioxins/furans in edible fish of the area. Presumably, implementation of the sand cover of the dioxins/furans in Old Mormon Slough sediments will represent the implementation of the TMDL. There are several questions about the long-term reliability of this remediation approach. Of particular concern is the adequacy of the proposed monitoring of the integrity of the sand cover and its ability to prevent dioxin/furan release to the overlying waters, where they could bioaccumulate in edible fish for as long as the dioxins/furans are present in the sediments.

Mercury

Mercury is a neurotoxin that is a threat to fetuses and young children. Mercury in its various forms is converted to methyl mercury at the sediment-water interface. Methyl mercury bioaccumulates in edible fish and, therefore, represents a threat to young children and pregnant women who consume fish containing elevated concentrations of mercury. Some fish taken from the SJR and the South Delta have been found to contain excessive concentrations of mercury compared to U.S. EPA and California Office of Environmental Health Hazard Assessment (OEHHA) guidelines for protection of human health. This has caused the CVRWQCB to list the SJR and South Delta as 303(d) impaired for mercury. The CVRWQCB is conducting studies to better define the approach for controlling excessive mercury bioaccumulation in SJR and South Delta fish. The mercury is derived from former mercury mines in the Coast Range that discharge waters to the SJR tributaries, as well as former gold mining activities in the Sierras, where the mercury that was used to help recover gold was lost to the soil and sediments of the area. This mercury is now being transported to the SJR and its tributaries. One of the potential sources of mercury is irrigation water that is used on agricultural lands.

An issue of concern is that sulfate influences the rate of methyl mercury formation at the sediment-water interface, and the SJR contains elevated concentrations of sulfate compared to concentrations found in delta waters that are derived from Sacramento River water. This could mean that movement of SJR water through the South Delta, and its associated sulfate, could influence bioaccumulation of mercury in edible fish in the South Delta.

There is an environmental justice issue associated with regulating excessive mercury bioaccumulation, in that current human health protection guidelines are based on a national average fish consumption rate. There are situations in the SJR and Delta where minorities, economically disadvantaged, and others are likely consuming more fish than the national average consumption rate. This could require that the allowable fish tissue concentrations of mercury be lowered to protect those who eat more fish than the national average.

Sanitary Quality

Sanitary quality of water is dependent on the presence of human pathogenic organisms derived from human and some animal fecal matter. In an effort to protect contact recreation in waters (swimming, wading, etc.), the U.S. EPA is requiring that states adopt a sanitary quality contact recreation standard based on *E. coli*. This standard has been shown to be more reliable in protecting human health than the fecal coliform standard that is widely used today. The CVRWQCB has adopted the *E. coli* standard recommended by the U.S. EPA. This standard, however, has not yet been approved by the SWRCB. There is need for the SWRCB to approve this *E. coli* standard in order for it to be implemented for Central Valley waters.

Waters of the SJR and DWSC in the city of Stockton have been listed as impaired for contact recreation because of excessive concentrations of pathogens. It is highly likely that the SJR and its tributaries, as well as some of the waters in the South Delta, also contain excessive concentrations of pathogens that are a threat to contact recreation. There is a need to more adequately evaluate the presence of *E. coli* in the SJR and South Delta waters, and list those waters as 303(d) impaired where concentrations of *E. coli* exceed U.S. EPA recommended concentrations.

In addition to the concern about the sanitary quality of water for contact recreation, there is also concern about using waters with elevated pathogen-indicator organisms (such as *E. coli*) as a domestic water supply source. With increased potential use of SJR and delta waters near Stockton for domestic water supply, there may be a need to more effectively control pathogen-indicator organisms at their sources, including runoff from agricultural lands, in order to protect domestic water supplies.

In addition to diseases caused by bacteria, such as typhoid, there are human diseases caused by protozoans, such as giardia and cryptosporidium, as well as viruses, which are a threat to human health through contact recreation. The *E. coli* standard does not adequately reflect the threat that these pathogens represent both to contact recreation and to the quality of domestic water supplies. Ultimately, agricultural interests in the SJR watershed, including those responsible for runoff from irrigated lands and dairies, feedlots, and managed public and private wildlife refuges, will need to control *E. coli* as an indicator of human pathogens in storm water runoff and tail water discharges.

Toxicity of Unknown Cause

Toxicity tests on SJR and delta waters using U.S. EPA recommended standard test organisms have shown the presence of aquatic life toxicity that is of an unknown cause. Since the presence of aquatic life toxicity is a violation of the CVRWQCB Basin Plan, this has caused the CVRWQCB to list the SJR and other waterbodies as impaired due to unknown-caused toxicity. As part of developing information needed to begin to formulate a TMDL to control this toxicity, the CVRWQCB has developed a research program focusing on developing toxicity investigation evaluations (TIEs) for selected pesticides used in the Central Valley. It is suggested that a more reliable approach for addressing the unknown-caused toxicity problem would be to focus the funds available on those situations where unknown-caused toxicity is currently found, and then, through a combination of TIEs and forensic studies, as well as information provided by the Department of Pesticide Regulation and the County Agricultural Commissioner on the use of pesticides in the watershed where unknown-caused toxicity is found, work to develop information on the cause of the unknown-caused toxicity.

Nutrients

Nutrients (nitrogen and phosphorus compounds) discharged from irrigated agriculture, and from agricultural and urban stormwater runoff and wastewaters, are causing significant water quality problems in the SJR and in the Delta, as well as in water utility water supply reservoirs that use delta water as a domestic water supply source. These problems are manifested through excessive growth of algae and/or water weeds such as water hyacinth and *Egeria*. At this time, the CVRWQCB's regulation of excessive fertilization water quality impacts is to be accomplished through a basin plan narrative water quality objective for the control of "biostimulatory substances." The CVRWQCB has not developed specific guidelines on how to evaluate the presence of excessive biostimulatory substances in a waterbody. However, at the request of the CVRWQCB staff, Lee and Jones-Lee (2002b) have provided guidance on the approach that can be used for implementation of the biostimulatory substance narrative water quality objective. Basically, this approach involves site-specific evaluation, for each potentially impacted waterbody of concern, of the desired nutrient-related water quality, the nutrient loads to the waterbody to achieve this water quality, and the sources of nutrients that need to be controlled to achieve the desired water quality.

The CVRWQCB Agricultural Waiver water quality monitoring program requires that agricultural interests subject to regulation under this program monitor nutrient concentrations at their monitoring locations beginning in the spring of 2006. Associated with this monitoring is the need to develop guidance on how agricultural interests and the CVRWQCB staff should interpret nutrient concentration data developed in the Agricultural Waiver monitoring program. This interpretation will need to be based on guidance provided by the CVRWQCB on implementing the narrative water quality objective for biostimulatory substances. Proper implementation of this objective will require a comprehensive monitoring/evaluation program of the impacts of the nutrients found at a particular monitoring point on water quality at that point and downstream. Through the agricultural waiver monitoring program, if adequately implemented, development of nutrient-control programs from irrigated agriculture and urban sources could begin to be developed in the SJR watershed and the delta.

It has been repeatedly demonstrated over the years that particulate phosphorus derived from land runoff is largely unavailable to support algal growth. It will be important in developing control programs for nutrients from agricultural and urban runoff to focus on available forms of phosphorus, rather than total phosphorus.

Aquatic Sediment Toxicity

Toxicity associated with aquatic sediments is becoming recognized as a potentially significant cause of water quality impairment. This toxicity can affect the numbers and types of benthic and epibenthic organisms, which are important components of fish food. Presence of aquatic life toxicity due to pesticides in sediments is a violation of the CVRWQCB Basin Plan that needs to be controlled. Of particular concern today is the finding that pyrethroid-based pesticides, which are being used in agricultural and urban areas as replacements for organophosphorus-based pesticides, not only cause toxicity in the water column during the time of discharge from areas where they are applied, but also cause toxicity in the sediments where they accumulate following a runoff event. This situation will ultimately require that agricultural and urban uses of pyrethroid-based pesticides (and any other pesticides that accumulate in aquatic sediments and cause aquatic life toxicity) be controlled.

Another source of sediment toxicity occurs in those sediments that accumulate dead algae, which create anoxic conditions in sediments through their decay. This leads to an accumulation of ammonia in the sediments, which is toxic to a number of forms of aquatic life. It also leads to low-DO conditions, which are also toxic to many forms of aquatic life. At this time, regulatory agencies at the federal and state level are largely ignoring the toxicity caused by nutrient discharges, which leads to growth of algae that die, settle, decay, and cause ammonia accumulation and anoxic conditions in sediments. This is the most important cause of sediment toxicity in some areas.

Currently the SWRCB is developing sediment quality objectives that ultimately will be used to regulate the discharge, to estuarine and marine waters and the delta, of pollutants that accumulate in sediments and cause sediment toxicity. Also of concern is control of sediments that serve as a source of bioaccumulatable chemicals, such as organochlorine legacy pesticides and PCBs. The SWRCB's efforts to develop sediment quality objectives are focusing on the integrated use of sediment toxicity, altered benthic organism assemblages compared to habitat characteristics, and chemical information. As discussed by Lee and Jones-Lee (2004b), it will be important that the chemical information be based not on total concentrations of chemicals (co-occurrence-based approaches), but on identifying the amounts of those chemicals that are causing aquatic life toxicity, serving as a source of bioaccumulatable chemicals, and/or altering benthic organism assemblages. The SWRCB has recently made available $2.5 million to develop sediment quality objectives for the delta, which includes the lower reach of the SJR. Ultimately this effort could significantly impact the discharges of chemicals from the SJR watershed that accumulate in the SJR sediments downstream of Vernalis (i.e., within the delta), which are adverse to the beneficial uses of the waters.

Some of the SJR DWSC sediments that have been dredged for maintenance of channel depth to enable ocean-going ships to reach the Port of Stockton have been found to be acid-producing when placed in situations such as in on-land dredged sediment disposal areas, as well as on a levee for levee stability enhancement. The acid-production situation associated with exposure of DWSC sediments to oxygen is another consequence of SJR watershed nutrients that lead to algal development that, upon their death and decay, leads to the accumulation of reduced forms of iron and sulfur in the sediments. Acid produced from these sediments arises from the oxidation of iron and sulfur compounds present in the sediments that, when in contact with oxygen, leads to low pH. This low pH can cause toxicity to aquatic life and can cause the release of heavy metals from the sediments, which can also be toxic to aquatic life. There is a need to more reliably evaluate how SJR DWSC sediments dredged from the navigation channel can be used for beneficial purposes, without adverse effects on water quality.

Heavy Metals

There is concern that heavy metals derived from the delta watershed, including the SJR watershed, such as copper and cadmium which tend to bioaccumulate in aquatic organisms, could cause toxicity to the host organism. These heavy metals are derived from former mining activities in the Sierra Nevada Mountains, and may not be adequately regulated by the current U.S. EPA and state water quality criteria/standards. This is an area that needs further study.

Pyrethroid Pesticides

Pyrethroid-based pesticides have been found to cause aquatic life toxicity in storm water runoff and other runoff/discharges from urban and agricultural areas where they have been applied, including in the SJR watershed. These pesticides accumulate in sediments following runoff events, causing sediment toxicity. Since water column and sediment toxicity are violations of the CVRWQCB Basin Plan, there is a need to begin to control use of pyrethroid-based pesticides that cause water column and/or sediment toxicity in the receiving waters for runoff from areas where they are applied. It is unclear, however, when the CVRWQCB is going to begin to control use of pyrethroid-based pesticides that are causing violations of the basin plan WQO. This is an issue that needs immediate attention by the CVRWQCB in order to avoid a long period of continued toxicity due to use of these pesticides.

Total Organic Carbon

Total organic carbon (TOC) content of a water that is to be used for domestic water supply is of concern since TOC interacts with many types of disinfectants (such as chlorine and ozone/bromide) to produce disinfection byproducts. These are chloroform-like chemicals that are regulated as carcinogens in domestic water supplies. The waters exported from the delta at the State Water Project (SWP) for domestic water supply use at times contain excessive concentrations of TOC compared to the U.S. EPA's regulatory limit. This requires water utilities to practice additional water treatment at additional cost.

One of the major sources of TOC for the delta is the SJR watershed. Within this watershed, the runoff from irrigated agriculture and discharges from wetland areas, including the large wildlife refuges, are major sources of TOC. Also, domestic and agricultural wastewaters and storm water runoff are sources of TOC. Another major source of TOC in the delta is delta island agricultural areas, associated with organics derived from the peat soils of many of these areas. Water utilities could reduce their cost of treatment if TOC were controlled at the various sources, which will be difficult to achieve.

At this time there are no water quality criteria or objectives covering TOC. This means that, even though the TOC in delta waters is causing impairment of these waters for use for domestic water supply, the waters with elevated TOC are not listed as CWA 303(d) impaired, with the result that there is no regulatory approach to control TOC discharges from various sources in the SJR watershed and within the delta. This situation could change if the CVRWQCB, as part of implementing the source water quality protection provisions of the U.S. EPA Safe Drinking Water Act, adopts a drinking water policy that includes development of a TOC water quality objective. Development of such a policy is under review by the CVRWQCB, where within a few years the board will likely consider a proposal to develop a WQO for TOC in Central Valley waterbodies. Adoption of a TOC WQO could have a significant impact on agricultural and urban interests and wildlife refuge (wetlands) managers in the SJR watershed, since they could be required to reduce the TOC content of their discharges/runoff.

Regulation of TOC should not be based on total concentrations. Some of the TOC that develops in the SJR watershed and within the delta, such as soluble BOD, is labile (non-persistent) and decomposes before reaching a water supply intake. Also of concern is the labile TOC in the form of algae, which die and decompose before the waters are taken for domestic water supply purposes by many of the water utilities that use delta water as a raw water source. It is important that TOC control programs focus on those sources of TOC that are refractory – i.e., do not decompose before reaching a domestic water supply intake.

One of the major issues that needs to be evaluated is whether controlling TOC at its sources is more appropriate than providing additional treatment at a water treatment facility to control the TOC at that location. About half of the water exported from the delta is for domestic water supply; the remainder is for agricultural use. The TOC in waters used for agricultural irrigation is not adverse to crop production; in fact, it may be beneficial.

TOC in South Delta waters impacts the potential use of these waters for groundwater recharge using aquifer storage and recovery (ASR) approaches. Elevated-TOC waters, which are acceptable for use in treated domestic water supplies, can be adverse to recharge of these waters through an ASR project, because of adverse impacts on the aquifer characteristics. Potential ASR projects, such as the one proposed by the city of Tracy based on Delta Mendota Canal (DMC) water (derived from the South Delta), should treat the water to remove TOC before injection into the aquifer.

Suspended Sediment

Some agricultural lands on the west side of the SJR are subject to severe erosion, resulting in runoff waters from these lands containing high concentrations of suspended sediments, which leads to highly turbid waters and shoaling/siltation where the sediment settles in the delta. While this is a significant water quality problem, the CVRWQCB has not listed the SJR as impaired due to suspended sediment/turbidity.

Efforts are being made by some of the agricultural interests where erosion is occurring to control erosion through the addition of polymers to the soil. It is important that chemicals used to control erosion be adequately evaluated to be certain that they do not cause water quality problems in the SJR, its tributaries, and the delta.

There is a significant problem with the way in which the CVRWQCB Basin Plan evaluates excessive suspended sediment/turbidity in waters. This needs to be addressed in order to develop a more readily implementable approach for evaluating excessive suspended sediment and turbidity in a waterbody.

An issue of concern is that control of turbidity in the SJR could lead to increased planktonic algal growth in the SJR, which could increase the oxygen demand load that the SJR discharges to the DWSC. At this time, growth of algae in the SJR is light-limited. With reduced turbidity, there could be increased growth of algae, since surplus nutrients are available to support this growth.

Herbicides

Toxicity testing of the waters in the SJR watershed and delta has shown that some samples of these waters are toxic to the U.S. EPA standard toxicity test alga (*Selenastrum capricornutum*). TIE studies have shown that at least part of this toxicity is due to diuron, a widely used herbicide for controlling terrestrial weeds in some fields and along highways. Toxicity to algae is a violation of the CVRWQCB Basin Plan, which requires control. At this time, the CVRWQCB has not listed algal toxicity as a CWA 303(d) water quality impairment, and therefore no work is being done to control the algal toxicity that is being found in the SJR watershed and delta. This is an issue that will need to be addressed in future CVRWQCB activity.

Algal toxicity that is being found is often in waterbodies that have excessive growth of algae. It appears that herbicide effects do not cause sufficient toxicity to greatly reduce algal biomass in the SJR watershed and South Delta. However, there is a potential for algal toxicity in the SJR to affect concentrations of algae that represent oxygen demand loads to the DWSC. This situation could create pulses of algae, which would make managing the low DO problem in the DWSC more difficult and expensive as a result of requiring a more intensive monitoring program to assess oxygen demand loads to the DWSC.

Unrecognized Pollutants

There is increasing concern about pharmaceuticals and other unregulated chemicals from confined animal facilities (CAFs) and from domestic wastewaters to cause water quality problems in the receiving waters for discharges from these areas. The current approach for monitoring potential pollutants in the SJR and delta is significantly deficient in that it considers only a hundred or so chemicals of the many tens of thousands of chemicals that are discharged to these waters from urban and agricultural sources. Pharmaceuticals and personal care products (PPCPs) are discharged to wastewater systems, which enter surface and ground waters receiving domestic and agricultural wastewaters. For example, pharmaceuticals that are used at CAFs (such as dairies, feedlots, etc.) and are discharged in domestic wastewaters are unregulated chemicals, from a water quality impact perspective, that have the potential to be significantly adverse to aquatic life. Adverse impacts of these chemicals on aquatic life are being found. There is a need, however, to greatly expand the scope of potential pollutant-monitoring programs to more adequately identify chemicals that could be adverse to aquatic life and other beneficial uses of waterbodies. This monitoring should focus on those areas near where domestic and agricultural wastewaters are discharged to surface waters in the delta and SJR tributaries. Studies conducted at the University of California, Davis (UCD) have demonstrated sublethal impacts of chemicals in SJR and delta waters. There is need to better understand the water quality significance of these biomarker responses.

Overall

The SJR, many of its tributaries, and those parts of the delta that receive SJR water are highly impacted by known pollutants derived from irrigated agriculture, other agricultural activities involving animal husbandry, public wetland wildlife refuges and private gun clubs, and urban storm water and wastewater discharges. These impacts on the beneficial uses of SJR waters and the delta are significantly affected by SWRCB Water Rights decisions that allow water diversion/exports. The ability of the CVRWQCB to address these problems is greatly hampered by a lack of funding from state and federal sources.

There is an urgent need to develop a large-scale water quality monitoring/evaluation program to address known water quality impairments, as well as to identify other water quality impairments that are not now recognized. Without such a program, the ability of the CVRWQCB to adequately restore the SJR, its tributaries, and the delta to unimpaired beneficial uses will be limited. Funds to support this monitoring, evaluation, and management program should be derived from all who discharge wastewaters and storm water runoff to the SJR tributaries and the SJR, and all who derive benefits from using SJR watershed waters.

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WET AND DRY ATMOSPHERIC DEPOSITION OF PESTICIDES IN THE SAN JOAQUIN VALLEY, CALIFORNIA

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Abstract
Wet- and dry-atmospheric deposition samples were collected at six sites in the San Joaquin Valley, California, over two and a half years. Wet-deposition samples were collected from individual rain events, and dry-deposition samples were composites collected over periods of three weeks to four months. Samples were analyzed for 41 currently used pesticides and 23 transformation products, including the oxygen-analogs of nine organophosphorus insecticides. Ten compounds in rainfall and 19 in dry deposition were detected in at least 50% of the 157 samples collected. Herbicides dacthal, pendimethalin, simazine, and trifluralin, and insecticides chlorpyrifos, diazinon, and carbaryl were the most frequently detected pesticides in both rainfall and dry deposition. The oxygen-analog concentrations in rainfall were at times equivalent to or greater than the parent concentrations. The significance of wet- vs. dry-depositional amounts was closely related to the Henry's law value of each compound. Observed trends for those compounds with low Henry's law values such as diazinon (0.04 pascal meter cubed per mole [Pa m^3/mol]) showed rainfall as a more important source of depositional loading to the ground. Dry deposition was a more predominant depositional pathway for those compounds with high Henry's law values such as chlorpyrifos (1.1 Pa m^3/mol).

Key words: pesticides, wet-and-dry atmospheric deposition, San Joaquin Valley, Henry's law

GIS AND META-ANALYSIS: TECHNIQUES FOR SITE-SUITABILITY ANALYSIS OF AGRICULTURAL BEST MANAGEMENT PRACTICES

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Abstract

Organophosphate insecticides, notably chlorpyrifos and diazinon, are used to maintain high levels of agricultural production in West Stanislaus County, California. Irrigation and storm water runoff carries some of the applied pesticides into surface waters, where water quality in the San Joaquin River and Delta can be impaired. Previous studies focused largely on pesticide loads from dormant orchard spraying coupled with winter rain events. Results from these studies suggested that pesticide loads to the San Joaquin River and Delta from eastern tributaries occurred mostly in the winter. In this meta-analysis, we combined 12 years of water monitoring, pesticide application, agricultural land use, rainfall, and stream discharge data to characterize seasonal trends and identify "hotspots" where best management practices (BMPs) could have the greatest impact on non-point source pollution. BMPs have demonstrated the ability to remediate agricultural runoff; the greatest net effect on watersheds will be achieved when BMPs are optimally sited to intercept non-point source pollution. Meta-analysis results were incorporated with traditional cartographic modeling techniques and GIS site-suitability analysis to identify sites most suited for new BMPs. Nearly 4000 individual chlorpyrifos and diazinon measurements were compiled from five sites on the San Joaquin River and six sites on tributary creeks. Pesticide application data was spatially processed and analyzed using GIS software. Year-round chlorpyrifos and diazinon stream concentration and loading was compared with pesticide applications within one mile of Orestimba Creek. At Orestimba Creek at River Road, of the 191 samples which exceeded the California Department of Fish and Game Criterion Continuous Concentration of 0.014 μg/L chlorpyrifos, 67% were in the dry summer season. Contrary to previous studies on eastern tributaries of the San Joaquin River, western tributaries are more affected by summer growing-season pesticide applications than winter applications. Westside summer flows are made up almost entirely of irrigation return flows. Four, one-square-mile sections adjacent to Orestimba Creek in extreme southwest Stanislaus County were identified as the most promising candidates for future BMP construction. Future focused studies and enhanced spatial data will improve resolution for BMP site selection.

Key words: BMPs, GIS, pesticide, San Joaquin River, Central Valley California, water quality

A METHODOLOGY TO EVALUATE AND OPTIMIZE EFFECTIVENESS OF NON-POINT SOURCE POLLUTION ABATEMENT PROGRAMS

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Abstract

Atrazine concentrations were detected at levels exceeding water quality standards in Hoover Reservoir, Central Ohio's largest drinking water supply. A partnership was formed between the city of Columbus and agricultural watershed community. USDA has allocated more than $13 million dollars for farmers to implement conservation measures (BMPs). Since implementation, farmers, the city, program managers, and policy makers have questioned the program's effectiveness. A probabilistic risk assessment characterized the occurrence and magnitude of atrazine in Hoover Reservoir before and during the USDA conservation program. Statistical analysis of water quality data suggests significant atrazine reduction during program implementation. USDA's National Agricultural Pesticide Risk Analysis (NAPRA) model was used to simulate atrazine runoff for 50 years of historical climatic conditions, 135 BMP scenarios, three loss pathways, 44 soils, and 2,968 crop fields. GIS was used to integrate NAPRA output data into the watershed's crop fields to estimate and compare annual atrazine losses among BMPs, map and illustrate the distribution and effectiveness of BMPs by crop field, and compare total watershed annual loading with measured atrazine data in Hoover Reservoir. The USDA conservation program reduced annual atrazine loads an average of 83.6%. Probabilistic risk assessments verified reduced human health and ecological exposure risk from 10% to 0%. Applications of this methodology will help local conservation planners identify critical areas, specific conservation measures to implement for each crop field, and a process to evaluate and optimize the water quality performance of watershed-scale, non-point source pollution abatement programs.

Key words: atrazine, BMPs, drinking water supply, partnership, probability risk assessment, water quality

WATER QUALITY NEAR AGRICULTURAL LAND IN THE SNOQUALMIE WATERSHED, KING COUNTY, WASHINGTON

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Abstract
Land use in the Snoqualmie Watershed is 92.6% agricultural or rural residential. The King Conservation District (KCD) educates farmers on best management practices (BMPs) to protect water quality and salmon habitat. Under contract to the KCD, the King County Water and Land Resources Division monitored water quality at a total of 13 sites near agricultural land in five salmon-bearing tributaries to the Snoqualmie River. The project goal was to identify where water quality problems persist. Monitoring occurred on 24 dates from August 2005 through April 2006. The KCD will use the data to prioritize locations for development of BMPs. Temperature, dissolved oxygen, pH, turbidity, fecal coliform bacteria, and nutrients (nitrogen and phosphorus) were measured at each monitoring site. Selection of parameters and sites was based on past violations of state water quality standards. The data indicate continuing violations of standards for dissolved oxygen, pH, and fecal coliform bacteria. There were some violations at each site; Ames Creek sites had the highest frequency of water quality problems and the highest turbidity and nutrient levels. Water quality should be monitored at all sites after implementation of BMPs to evaluate their success, thereby further helping the KCD to target technical assistance to farmers.

Key words: best management practices, farmers, monitoring, salmon habitat, water quality

Introduction and Project Background

The Snoqualmie Watershed is contained mostly within King County, extending from river valleys east of Seattle to the crest of the Cascade Mountains (Figure 1). The watershed contains some of the healthiest aquatic habitat remaining in King County and supports wild populations of chinook, coho, chum, and pink salmon; steelhead, rainbow, and cutthroat trout; and native char, i.e., Dolly Varden and bull trout (King County, 2001; Snohomish Basin Salmonid Recovery Technical Committee, 2004; Washington Department of Fish and Wildlife and Western Washington Treaty Indian Tribes, 1994). Snoqualmie Falls, near the city of Snoqualmie, is a natural barrier to the migration of these anadromous species.

Land use downstream of Snoqualmie Falls is 70.4% agricultural and 22.2% rural residential. From 1980 to 1999, the population in the watershed nearly doubled from approximately 20,000 to 38,000 people. The Puget Sound Regional Council predicts that the population will grow to more than 70,000 residents by 2020 (King County, 2001).

Many of the people moving to the Snoqualmie Watershed are from urban areas and do not have prior experience owning small farms and livestock. Among these newcomers and some long-time agricultural landowners, there is a lack of knowledge about potential impacts of farming practices on water quality. Therefore, many of the farms are overgrazed and streams are often used as a sole source of water for the livestock. The consequences are streambank erosion; trampling of riparian vegetation; decreased effectiveness of the riparian corridor to shade and cool the water; and increased discharge of sediment, nutrients, and bacteria to the water.

Previously collected water quality data (Haring, 2002; Joy, 1994; Solomon, 2005; Washington Trout, 2000) indicate that instream temperatures, dissolved-oxygen (DO) levels, pH measurements, and fecal coliform (FC) bacteria counts violate state of Washington water quality standards (WQS) in tributaries to the Snoqualmie River. Some instream temperatures that meet state WQS are higher than the optimal salmon spawning and rearing temperature range of 10°C to 13.9°C (Bjornn and Reiser, 1991).

The King Conservation District (KCD) received a grant from the Washington Department of Ecology (WDOE) to work with livestock farmers in the Snoqualmie Watershed on best management practices (BMPs) related to protection of water quality and salmon habitat. Several approaches will be used including workshops, farm tours, farm plans, technical assistance, cost-share funding, and educational materials.

The KCD hired the King County Water and Land Resources Division (WLRD) to perform the water quality monitoring component of the overall project. The water quality monitoring goal is to identify where water quality problems persist, i.e., where WQS are violated, near agricultural land in the Snoqualmie Watershed. The KCD will use the data to prioritize locations for source tracing and BMPs, and to educate landowners about the effects of their land-use decisions on water quality.

Methods

The project initially targeted four salmon-bearing tributaries to the Snoqualmie River – Cherry Creek, Harris Creek, Ames Creek, and Patterson Creek (Figures 2 and 3). These streams drain agricultural land; past data indicate water quality and salmon habitat problems related to small farms and livestock. One month after the project began, King County WLRD added a fifth tributary in response to a request from the KCD and local residents. This is an unnamed tributary near Adair and Wallace Creeks and salmon-bearing Horseshoe Lake (Figure 3).

King County WLRD selected three monitoring sites on Cherry, Harris, Ames, and Patterson creeks and one monitoring site on the unnamed tributary for a total of 13 sites (Figures 2 and 3). For each named creek, one site (Cherry 1, Harris 1, Ames 1, and Patterson 1) was near the mouth, downstream of large farms, at public road crossings or on public land, and at the same location that was monitored for water quality by the WDOE from 2003-2005. The other sites were further upstream on each creek, but downstream of rural residential land and hobby farms. The more eastern sites were called Cherry 2, Harris 2, Ames 2, and Patterson 2; the more western sites were called Cherry 3, Harris 3, Ames 3, and Patterson 3. The unnamed tributary site was downstream of a large housing development and several farms. Four of the upstream sites were on private land. The landowners granted permission to King County WLRD to access their property to perform water quality monitoring.

King County WLRD field staff used Hydrolab equipment to measure temperature, DO, and pH, and a Hach 2100P turbidity meter to measure turbidity at each site. They also collected water samples from the deepest part of the stream at each site for laboratory analyses of FC bacteria, total nitrogen (TN), and total phosphorus (TP). The selection of water quality parameters was based on past violations of state WQS (Washington Department of Ecology, 1997) and on knowledge about nonpoint pollution from agricultural sources.

The project team followed King County standard operating procedures (King County, 2005) and quality assurance/quality control protocols (King County, 2004) for collection and analysis of water samples. All parameters were measured in the same order at approximately the same time on each sampling date so that valid comparisons could be made over time. All parameters were duplicated at a rate of approximately 10%, resulting in a total of 13 samples per event (12 sampling sites and one field replicate).

Water quality monitoring took place 12 times (semi-weekly or weekly) during the dry, low-flow season from late August through October of 2005 and 12 times (biweekly) during the wet, high-flow season from November of 2005 through early April of 2006.

Weather conditions affected progress with the monitoring. There were dry channels at the two upstream sampling sites on Harris Creek on the first two sampling dates. Therefore, the project team selected two new upstream sites that had sufficient flows. Winter floods prevented access to the upstream sites on Ames Creek on two sampling dates. Sampling at these sites took place on the next available days when there was safe access.

Results and Discussion

Temperature

The state WQS for temperature is $\leq$18ºC for protection of aquatic life (Washington Department of Ecology, 1997). The WQS was met at all sites on all dates. However, monitoring started in late August. The hottest time of the year in western Washington is late July and early August. If monitoring had begun then, there might have been violations of the temperature WQS.

The water temperature exceeded 13.9ºC at some sampling sites from late August through the middle of September. Table 1 indicates that this occurred most frequently at the Cherry Creek sites. All three sampling sites were warmer than optimal for salmon spawning and rearing on August 25, August 30, and September 1.

Table 1. Sites where water temperature >13.9ºC in late summer, 2005.

8/25/05	*8/30/05*	*9/1/05*	*9/8/05*	*9/14/05*
Ames 3		Ames 2		Ames 2
Cherry (all)	Cherry (all)	Cherry (all)	Cherry 3	
Harris 1				
Patterson (all)	Patterson 2 Patterson 3			

Dissolved Oxygen

The state WQS for DO is >8.0 mg/L for protection of aquatic life (Washington Department of Ecology, 1997). Table 2 presents the range of DO levels and percentage of samples where the DO level was ≤ 8.0 mg/L in each of the five monitored streams. The highest percentage of WQS violations for DO occurred in the unnamed tributary and Ames Creek.

Table 2. DO range (mg/L) and percentage WQS violations.

Ames: 3.8-11.9	29.2%
Cherry: 6.0-13.7	12.5%
Harris: 8.0-13.0	1.5%
Patterson: 7.8-12.1	2.8%
Unnamed: 1.0-10.2	84.2%

In general, there is an inverse relationship between temperature and DO; more oxygen can dissolve in cooler water than in warmer water. However, DO levels did not meet WQS during both warm and cool weather during the sampling period. Low DO levels on cool days could result from the discharge of pollutants with a high biological oxygen demand.

pH

The pH of a waterbody indicates its acidity or alkalinity. On a scale of 1 to 14, a pH of 7 is neutral, below 7 is acidic, and above 7 is alkaline. The state WQS for pH is the range of 6.5-8.5 for protection of aquatic life and human health (Washington Department of Ecology, 1997). There were minor violations of the WQS at four sampling sites where pH measurements were 6.2, 6.3, or 6.4. The percentage of samples that violated the WQS for pH at each of these sites was as follows:

- Ames 1: 8.3%.
- Ames 2: 25%.
- Cherry 2: 4.2%.
- Unnamed tributary: 31.6%.

Fecal Coliform Bacteria

FC bacteria are found in the intestinal tracts of humans, other mammals, and birds. Although these bacteria do not cause disease, their presence in large numbers in a waterbody may indicate the presence of other, disease-causing bacteria.

The state WQS for FC bacteria is ≤100 colony-forming units in 100 ml of water (CFU/100 ml) for protection of human health (Washington Department of Ecology, 1997). FC bacteria counts exceeded 100 CFU/100 ml at some sampling sites on 22 of the 24 sampling dates (the exceptions were December 15, 2005, and April 5, 2006). Table 3 indicates the FC range in CFU/100 ml and the percentage of WQS violations in each of the five monitored streams. The maximum FC bacteria counts in Ames, Cherry, and Harris creeks were 10 to 24 times as high as the WQS. Almost half of the Ames Creek samples and more than one-third of the Patterson Creek samples had FC bacteria counts that violated the WQS. Possible sources of these bacteria are wastes from livestock, pets, and wild animals, and human sewage from failing septic systems.

Table 3. FC bacteria range (CFU/100 ml) and percentage WQS violations.

Ames: 2-2400	48%
Cherry: 1-1050	25%
Harris: 2-1800	21.2%
Patterson: 5-570	34.7%
Unnamed: 0-270	10.5%

Turbidity

Turbidity refers to the extent to which light is scattered by suspended sediment, silt, and organic matter in a waterbody. Turbidity is measured in nephelometric turbidity units (NTU), which refer to the type of instrument (nephelometer) used to estimate light scatter in water samples.

The state WQS for turbidity is used for assessing impacts of point discharges by comparing measurements upstream and downstream of a discharge point. Because this study collected baseline water quality data, the WQS is not applicable. Instead, dry season and wet-season turbidity means were compared for each stream and among the five streams.

Table 4 shows that Ames Creek and the unnamed tributary had the most turbid water during the dry season, and Ames and Patterson creeks had the most turbid water during the wet season. Turbidity was higher on wet-season sampling dates in all streams except for the unnamed tributary. In the latter, sampling began on September 27, 2005. Consequently, there were seven dry-season sampling dates and 12 wet-season sampling dates. If there had been 12 dry-season sampling dates, the mean dry-season turbidity measurement may have been less than the mean-wet season turbidity measurement.

Table 4. Dry and wet season mean turbidity measurements (NTU).

Creek	***Dry Season***	***Wet Season***
Ames	4.11	10.97
Cherry	2.37	3.93
Harris	1.25	1.57
Patterson	2.19	7.18
Unnamed	7.84	5.72

Nutrients

Nitrogen and phosphorus are required for plant growth and are present in fertilizers that are used in agriculture and on residential lawns and gardens. Livestock, pet, and wildlife waste and human sewage are other sources of these nutrients in waterbodies.

There are no state WQS for TN and TP in streams. Therefore, King County WLRD compared the range of TN and TP levels among the five streams and between the five streams and other, comparably sized King County streams that drain agricultural land.

Table 5 indicates that TN and TP levels were highest in Ames Creek and the unnamed tributary. Overall nutrient levels in the five streams were similar to those in the other King County streams. This does not mean that the nutrient levels in the study streams do not pose any problems for aquatic ecosystems or water quality; rather, the data indicate that the five study streams have "typical" nutrient levels.

Table 5. Range of TN and TP levels (mg/L).

Creek	***TN***	***TP***
Ames	0.521 – 3.68	0.032 – 0.275
Cherry	0.371 – 2.26	0.012 – 0.111
Harris	0.485 – 1.92	0.011 – 0.069
Patterson	0.349 – 3.04	0.017 – 0.088
Unnamed	0.685 – 6.62	0.043 – 0.175

Conclusions and Next Steps

Each of the 13 water-quality monitoring sites had violations of WQS on some sampling dates. The streams that had the overall worst and second worst water quality for each parameter were-

- Temperature – Cherry, Patterson
- D.O. – unnamed, Ames
- pH – unnamed, Ames
- FC – Ames, Patterson
- Turbidity – Ames, Patterson
- TN – unnamed, Ames
- TP – Ames, unnamed

The comparative data suggest that the KCD should focus its source-control efforts on farms located along Ames Creek, Patterson Creek, and the unnamed tributary. Comparing the data among the three sampling sites on Ames Creek and Patterson Creek showed that the Ames 1, Ames 2, and Patterson 3 sites have the most degraded water quality. Ames 1 was worst for FC bacteria counts and nutrient levels; Ames 2 was worst for temperature, DO, pH, and turbidity. The Harris Creek sites, especially Harris 2 and Harris 3, had the fewest violations of state WQS and lowest turbidity and nutrient levels. These upstream sites were outside the agricultural production district (Figure 3). These findings reinforce a linkage between agricultural land use and degradation of water quality.

The next steps in the overall KCD project are prioritization of farms for identification of pollution sources and development of a unique farm plan with source-control BMPs for each farm. King County WLRD will recommend that the KCD first visit the farms that are upstream of the Ames 1, Ames 2, and Patterson 3 sampling sites.

Microbial source tracing at each high-priority site, i.e., DNA analyses of FC bacteria in water samples, would provide information on whether the bacteria are coming from human and/or animal sources and the percentage of bacteria from each animal species such as cows, horses, poultry, geese, and dogs. If the bacteria are primarily from human sources, this suggests failing septic systems. Upgrading these septic systems would therefore be an important BMP. On the other hand, if the bacteria are primarily from livestock, this would suggest the need to implement BMPs to keep livestock and their wastes away from streams.

An important action in a future project would be to conduct follow-up water quality monitoring three to five years after implementation of the farm plans and BMPs in order to evaluate the success of the source-control and corrective actions. Hopefully there would be a decreased frequency of WQS violations and overall improvement in water quality in each of the five streams.

Acknowledgments

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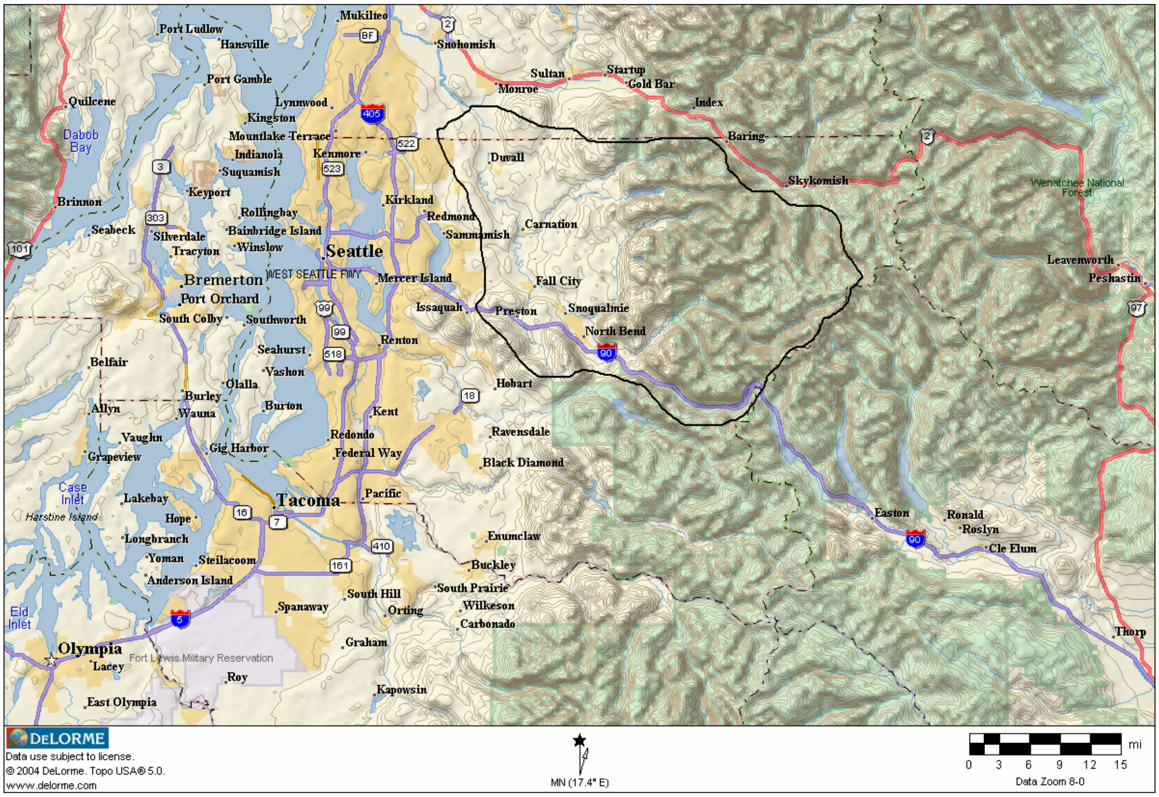

Figure 1. Greater Seattle area and Snoqualmie Watershed. The black line indicates watershed boundaries.

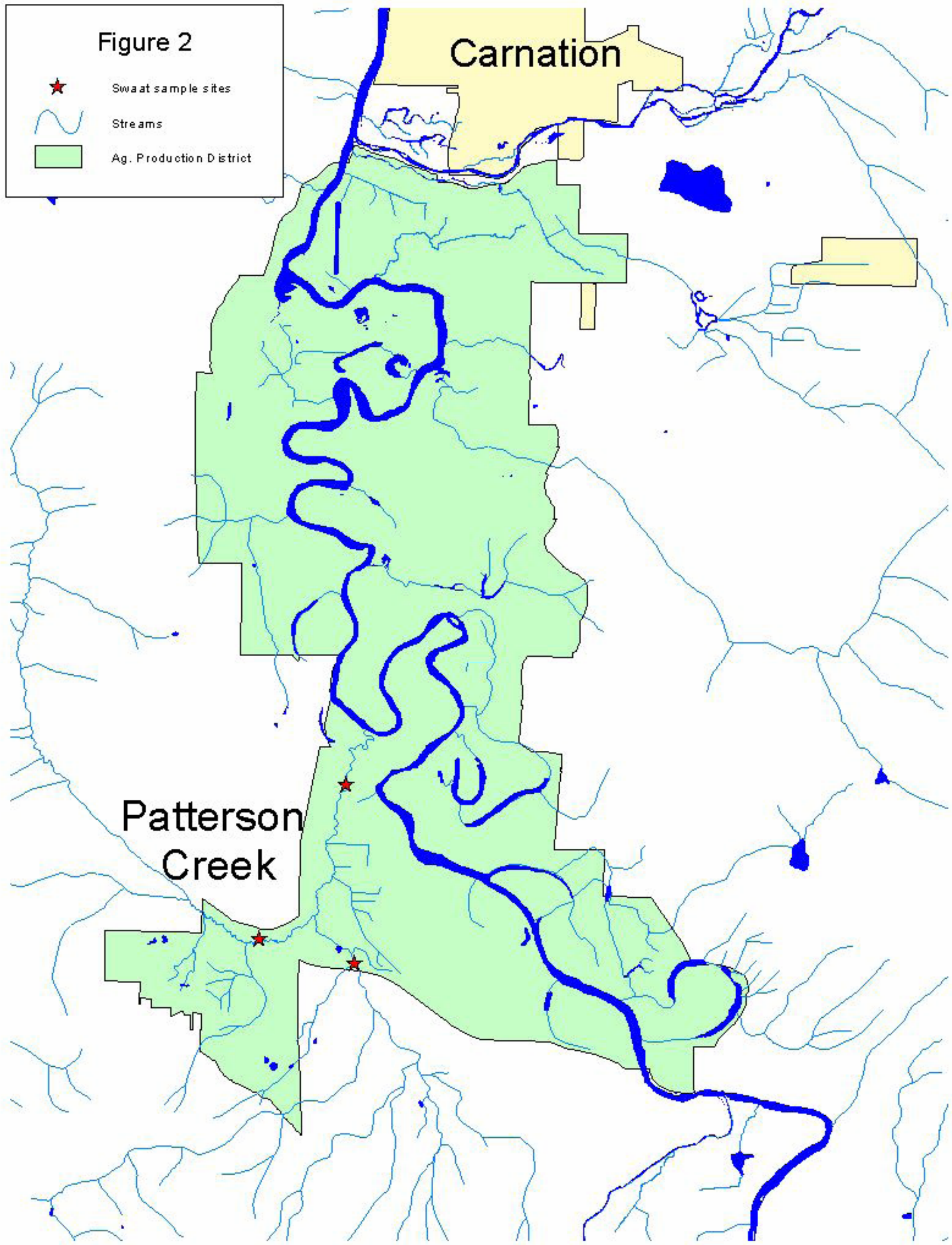

Figure 2. Location of monitoring sites in Patterson Creek. The thick blue meandering line is the Snoqualmie River.

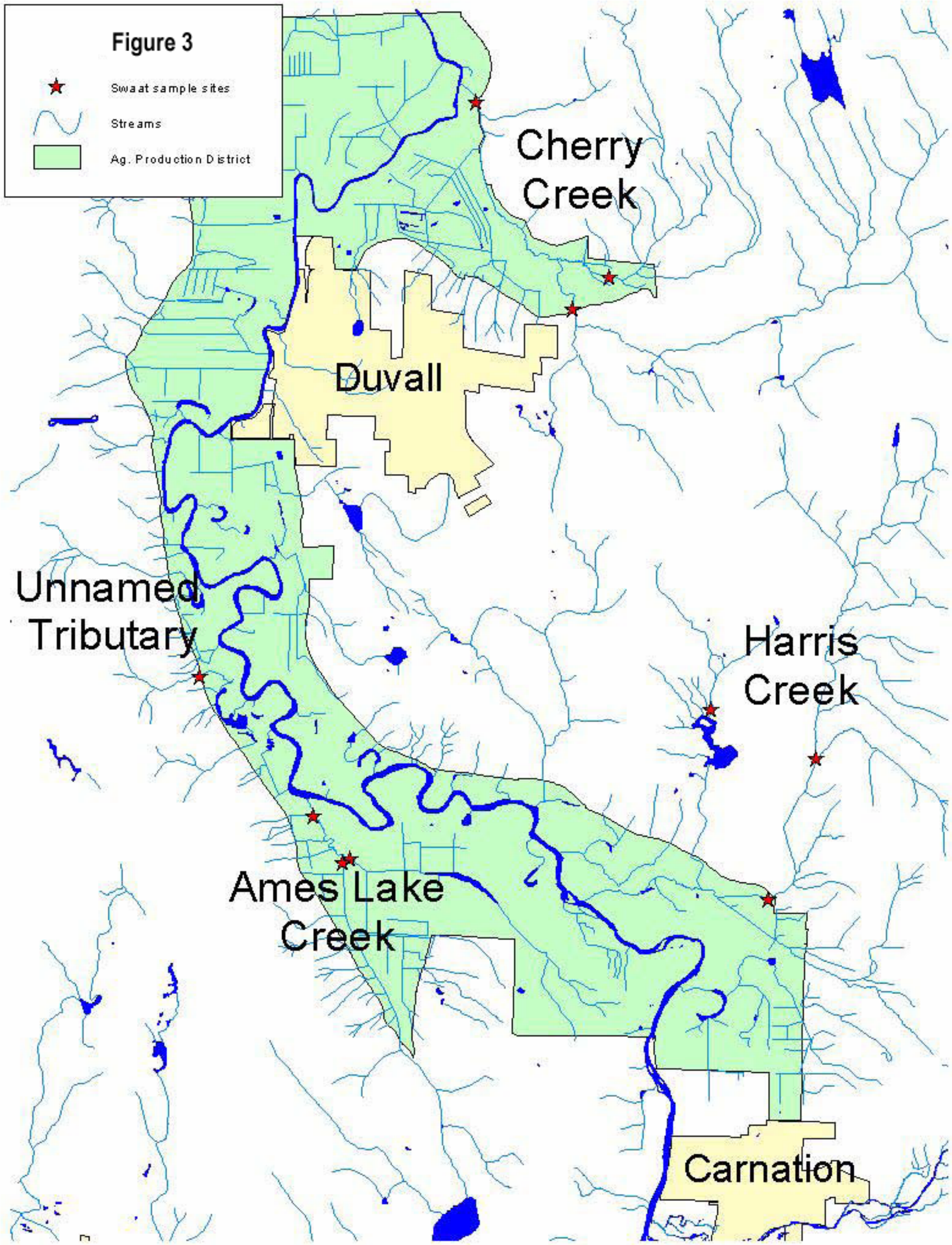

Figure 3. Location of monitoring sites in Ames, Harris, and Cherry Creeks and the unnamed tributary.The thick blue meandering line is the Snoqualmie River.

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TIME-SERIES ANALYSIS OF NEBRASKA DAILY RAINFALL TO COMPUTE THE RISK OF EXCESSIVE ATRAZINE LEVELS AT EIGHT DIFFERENT LOCATIONS, PARTICULARLY THE BIG BLUE RIVER BASIN

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Abstract

Measured atrazine concentrations in Nebraska surface water have been shown to exceed water quality standards, and a risk exists to humans and to the ecosystem. To assess this risk, atrazine runoff was simulated at the field-scale in Nebraska, based on the pesticide component of the model AGNPS. This project's objective was to determine the frequency that the atrazine concentration at the field outlet exceeded three different atrazine water quality criteria. The simulation was conducted for different farm management practices, soil moisture conditions, and five Nebraska topographic regions. If the criteria were exceeded, a risk to the drinking water consumer or freshwater aquatic life was hypothesized to exist. Three pesticide fate and transport processes were simulated with a calibrated model. Degradation was simulated using first-order kinetics. Adsorption/desorption was modeled assuming a linear soil-water partitioning coefficient. Advection was based primarily on the USDA-NRCS curve-number method. Daily rainfall from the National Weather Service was used to compute soil moisture conditions for the 1985-2000 growing seasons. After each runoff event, the pesticide runoff concentration was compared to each of the three different atrazine water quality criteria. Results show that environmental receptors are exposed to unacceptable atrazine runoff concentrations 20 to 50 percent of the time.

Key words: atrazine, exceedance probabilities,non-point source pollution, water quality

EAST SAN JOAQUIN WATER QUALITY FRAMEWORK: DEVELOPMENT OF EFFECTIVE MANAGEMENT PRACTICES TO PREVENT WATER QUALITY IMPAIRMENT– AN APPROACH

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Abstract

The East San Joaquin Water Quality Framework was created to provide a watershed organizational structure for cooperative and coordinated water quality improvement activities. The framework study area encompasses approximately 600,000 acres in the California San Joaquin Valley, including areas served by five irrigation districts: Oakdale, South San Joaquin, Modesto, Turlock, and Merced. Work conducted under the framework includes water quality monitoring, best management practices and implementation activities, and education and outreach to urban and agricultural communities. To focus water quality monitoring and implementation activities, the framework is conducting a comprehensive analysis of existing water quality data in the region. This includes 2000-2005 water-quality monitoring data collected by state, federal, and local agencies; cities and counties; NPDES permittees; irrigation districts; water quality coalitions; and universities and other entities. In addition, the analysis includes 2000-2005 spatially explicit pesticide use data, land-use information, and detailed watershed mapping. The analysis will provide insight into the nature of water quality issues and assist in developing specific recommendations for management practices and implementation strategies in the framework area. The following steps are being undertaken to identify, test, and implement management practices: determine nature of water quality impairment including pollutant of concern, land use, and practices contributing to impairment, and areas where these land uses and activities are concentrated; identify and develop candidate control measures for significant pollutants and associated land uses/practices; test the effectiveness of site-specific and land-use-specific control measures through pilot or demonstration projects as needed; develop guidance for implementation of effective management practices; provide technical and/or financial assistance to appropriate entities or individuals; and implement effective management practices that are targeted to identify water quality issues.

Key words: San Joaquin, water quality, management practices, pesticides

LARGE-SCALE ECOSYSTEM STUDY OF ALGAE BIOKINETICS AS A FUNCTION OF NON-POINT SOURCE DISCHARGE IN CALIFORNIA'S CENTRAL VALLEY

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Abstract
It has long been known that excessive accumulation of algal biomass can lead to degradation of water quality. However, control and regulation of algal pollution is complicated, since algal biomass is not a conserved substance. The state of California is implementing a total maximum daily load (TMDL) requirement for oxygen demand on the San Joaquin River (SJR) in the Central Valley of California to deal with low dissolved oxygen levels in the Stockton Deep Water Ship Channel (DWSC) and locations within the Sacramento-San Joaquin Delta. The TMDL sites as possible causes for the low dissolved oxygen levels 1) loads of oxygen demanding substances from upstream sources, 2) channel geometry of the DWSC, and 3) reduced flows through the DWSC. The TMDL also states that solution of any one of these causes should solve the problem. The TMDL requires that those responsible for non-point discharges to the SJR perform studies to identify and quantify sources of oxygen-demanding substances. Monitoring activities have identified specific tributaries as sources of algae biomass to the SJR. It has been proposed that focusing efforts specifically on controlling algal loads from those tributaries would be one strategy for meeting watershed TMDL requirements and that a watershed-wide nutrient control plan would be ineffective, since nutrient concentrations in the SJR are many times higher than those limiting algal growth. Rationale for this approach is dependent on assumptions concerning the rate of algae growth in the SJR and the algal growth model being applied (e.g. exponential versus logistic). Current understanding of algal growth and yield (biokinetics) in the SJR is limited. A large-scale ecosystem study with funding from the California Bay-Delta Authority under Proposition 13 has been initiated to improve understanding of how non-point source discharges influence algal biokinetics. The study approach is to use a monitoring network to collect high-resolution spatial and temporal data with the objective of calculating a mass balance for algae. The network data is being combined with laboratory and field studies to resolve outstanding issues concerning patterns and rates of algae growth in the river and nature of algal growth limitations in this ecosystem. Results from initial studies examining algal biokinetics in both the tributaries and main-stem of the river will be presented. The implication of these findings for control of algae in the SJR will be discussed.

Key words: TMDL, dissolved oxygen, nutrients, eutrophication, algae, water quality

EVALUATION OF WATER QUALITY IMPACTS AND COMPARATIVE COSTS FOR INVASIVE, NON-NATIVE WEED CONTROL

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Abstract

Non-chemical and chemical techniques were evaluated for emergent, floating and terrestrial weeds at six locations in northern California. Targeted pest species included emergent weeds cattails (*Typha latifola*) and bulrush (*Scirpus acutus*); floating weeds primrose (*Luwigia peploides*) and duckweed (*Lemna minor*); and the terrestrial weed blackberry (*Rubus armeniacus*). In one case, Eurasian watermilfoil (*Myriophyllum* spicatum), a submersed weed, was targeted with floating weeds. Evaluation focused on water quality impact, efficacy, and cost-effectiveness. Weed abatement techniques evaluated were goat grazing, mechanical removal, chemical treatment followed by mechanical removal, and manual removal by labor crews using power equipment. Water quality impacts observed during implementation of non-chemical controls were largely transitory. The most significant impacts to water quality during weed abatement with goats were the temporary presence of coliform and *E. coli* above maximum concentrations allowed for recreation. If short-term increases in coliform and E. coli are acceptable, use of goats is a viable alternative. Use of goats and herbicides are preferable to use of manual removal techniques. Although effective, manual weed removal is expensive, extremely labor intensive, subjects workers to a high-injury potential, and must be repeated annually.

Key words: weed abatement, goat grazing, mechanical removal, manual labor, chemical treatment, water quality

BENEFITS OF VEGETATED AGRICULTURAL DRAINAGE DITCHES (VADD) AS A BEST MANAGEMENT PRACTICE IN YOLO COUNTRY, CALIFORNIA

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Abstract

Widespread contamination of California water bodies by the orthophosphate insecticides diazinon and chlorpyrifos is well documented. While their use has decreased over the last few years, a concomitant increase in pyrethroid usage (replacement insecticides) has occurred. Researchers have also documented diazinon toxicity pulses in California's Central Valley due to dormant orchard drainage. Vegetated agricultural drainage ditches (VADD) have been proposed as a potential economical and environmentally efficient management practice to mitigate the effects of pesticides in dormant season runoff. VADD have been effective in mitigating simulated pyrethroid runoff storm events in the Mississippi Delta; however, California poses a different scenario in timing of runoff (winter), rainfall intensity, and ditch vegetation and soil types. Multiple lines of evidence will be required to determine the effectiveness of VADD as an applicable management practice in California. This research will incorporate temporal and spatial sampling and chemical testing of water, sediment, and plants, in addition to ditch biological assessments and toxicity evaluations. Initial data will provide baseline information for model generation to predict necessary ditch conditions for appropriate pesticide mitigation. Utilizing a multidisciplinary team approach, the effectiveness of VADD in California will be determined. Such economical and environmentally successful management practices will offer farmers, ranchers, and landowners a viable alternative to more conventional (and sometimes expensive) practices currently suggested by conservation organizations.

Key words: VADD, orthophosphate insecticides, pyrethroid runoff

INTEGRATING PHYTOREMEDIATION, WETLANDS, SPRAY IRRIGATION, AND PRAIRIE RESTORATION TO TREAT CARBON TETRACHLORIDE CONTAMINATION IN A RURAL COMMUNITY

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Abstract

In a cooperative conservation effort, the U.S. Department of Agriculture is cleaning up a contaminated aquifer in a rural community and simultaneously improving the community's recreational and educational opportunities. While one component of the cleanup system irrigates school athletic fields that were parched and bare in previous summers, other components have created a nearby public recreational area. The USDA's other partners in this effort are the U.S. Department of Energy's Argonne National Laboratory (ANL) and the U.S. Environmental Protection Agency, Kansas State University, state regulators; and local businesses, governmental units, and residents. The groundwater aquifer beneath Murdock, Neb. became contaminated with carbon tetrachloride as the result of fumigation of grain stored decades ago in a USDA facility. The contaminant levels in the groundwater (up to 7,800 µg/L at one time) precluded use of the aquifer for drinking water, and discharge of contaminated groundwater to a nearby creek posed health risks. Concentrations of carbon tetrachloride as high as 361 µg/kg in subsurface soil indicated the presence of a soil source. Model simulations of potential leaching indicated that the source would continue to release contaminant for at least 80 years, and migration to the creek would continue after that. The USDA, ANL, and EPA developed an innovative cleanup system that combines multiple technologies. Near the contamination source, pumps extract contaminated groundwater and pass it through a spray irrigation system that dissipates the carbon tetrachloride harmlessly into the air. The treated water irrigates the school's athletic field, nurturing a healthy grassy surface. Supplementing the spray irrigation technology are more than 2,000 trees planted downstream from where the groundwater enters the creek. The trees accomplish phytoremediation by taking up contaminated water and breaking down carbon tetrachloride naturally. Native prairie plants around and between the trees intercept rainwater and force the trees to draw most of their water from the aquifer. The partners are restoring a downstream wetland to intercept lingering traces of carbon tetrachloride and are installing an ADA-accessible public trail through both the tree plantation and the wetland. Interpretive signs will enhance the visitor's experience and facilitate use of the site as an outdoor "living" classroom for the local school district. The landowners have welcomed this public outreach aspect of the project. In addition, a visiting scientist program brings technical experts into the school to explain the cleanup effort and answer questions. The EPA has approved a monitoring plan to follow the progress of the cleanup effort and ensure the protection of human health and the environment.

Key words: carbon tetrachloride, phytoremediation, spray irrigation treatment, wetlands, water quality

Introduction

This paper describes the environmental investigation and integrated remedial approach implemented at a U.S. Environmental Protection Agency (EPA) Superfund site at Murdock, Neb. in the east-central part of the state (Figure 1). During the 1950s and 1960s, the U.S. Department of Agriculture (USDA) applied fumigants containing carbon tetrachloride to grain in storage facilities at Murdock and throughout the U.S. Midwest. Entering the environment either because of spillage or methods of application, the fumigants migrated through the near-surface and unsaturated vadose zone soils into groundwater. The Commodity Credit Corporation of the USDA (CCC/USDA) supports an ongoing program to characterize the nature and extent of the carbon tetrachloride contamination and to determine and implement the most appropriate and cost-effective methods for protecting public health while remediating and restoring critical groundwater resources.

Site Description and Regulatory History

The village of Murdock lies between the state capital city of Lincoln, Neb. and the financial centers and military facilities at and near Omaha, Neb. (Figure 1). The village occupies approximately 80 acres in Cass County. Murdock's current population of 296 is increasing because of its proximity to the two urban centers.

In 1983, during routine testing of the Murdock public water supply system, the Nebraska Department of Health identified carbon tetrachloride at concentrations above the maximum contaminant level (MCL) of 5 µg/L, considered acceptable for drinking water under both state and federal regulations.

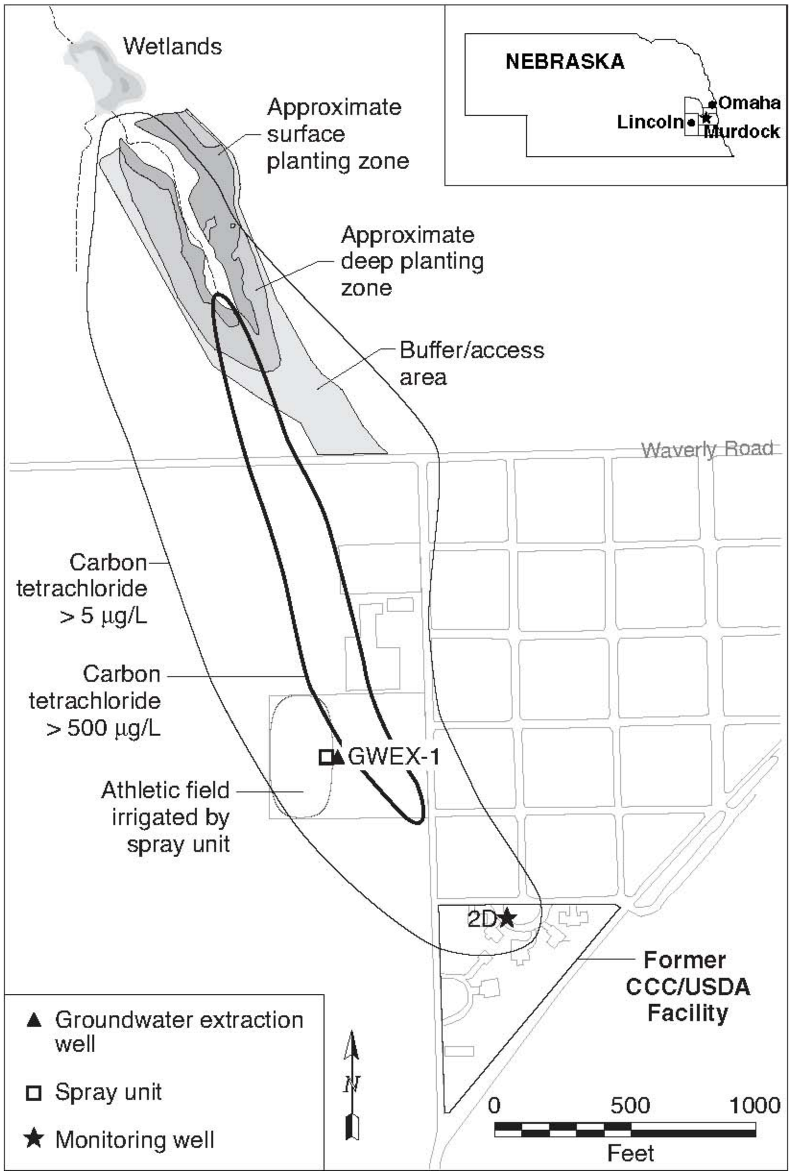


Figure 1. Locations of the carbon tetrachloride plume in groundwater at Murdock (2005 values) and the treatment systems installed for site cleanup.

In February 1986, the EPA conducted an immediate removal action, and the village was connected to a nearby municipal water distribution system. Additional EPA studies identified the five-acre grain storage facility formerly leased by the CCC/USDA as the source of the carbon tetrachloride contamination in the village's public wells. In 1991, the EPA and the CCC/USDA established requirements for further investigation and restoration of this site (EPA, 1991). Since 1991, the CCC/USDA has directed Argonne National Laboratory to perform a series of technical investigations to determine the distribution and monitor the extent of the carbon tetrachloride contamination in the subsurface at Murdock.

Carbon tetrachloride is a toxic pollutant that can reasonably be anticipated to be a carcinogen (ATSDR, 2006a). The clear liquid is moderately soluble in water and evaporates readily from surface water. Carbon tetrachloride that enters the soil may become adsorbed to soil organic matter. The compound is moderately mobile in most soils, depending on organic carbon content, and it can leach into groundwater. Research has shown little tendency for carbon tetrachloride to bioaccumulate in aquatic organisms (ATSDR, 2006b).

Characterization of the Murdock Contamination Site

The numerous characterization studies conducted by both the EPA and Argonne on behalf of the CCC/USDA have demonstrated that carbon tetrachloride contamination is present at Murdock, as follows (Figure 1):

- In the near-surface and deeper unsaturated (vadose zone) soils associated with the former CCC/USDA grain storage facility
- In a plume of contaminated groundwater originating at the former CCC/USDA facility and extending beneath the western margin of the town
- In surface waters and groundwater seepage in the headwaters area of the unnamed tributary to Pawnee Creek, northwest of the town

The Murdock aquifer is 20–30 ft thick and underlies most of the town at a depth of 50 ft below ground level (BGL). The plume emanating from the former CCC/USDA facility extends to the northwest, passing under Waverly Road (Figure 1). There the surface topography begins to be sharply downcut as a result of erosion of the Pleistocene sedimentary layers overlying the aquifer zone. Consequently, the depth to the water-bearing zone decreases markedly with progression to the northwest. The groundwater and associated contamination eventually enter directly into the surface waters of the creek.

Activities in support of the Murdock site characterization included surface geophysical studies, hydrogeologic and geophysical logging, groundwater sampling of investigative borings, aquifer pump testing, sampling and analysis of water from the public water supply wells and local private wells, installation and sampling of permanent monitoring wells and periodic measurement of water levels, vertical-profile sediment and groundwater sampling, stratigraphic logging with direct-push (cone penetrometer) techniques, and sampling of surface waters and groundwater seepage in the vicinity of the unnamed tributary to Pawnee Creek northwest of the town. Results of these investigations formed the basis for both initial and targeted model simulations of groundwater flow in the area.

Contamination in Near-Surface and Vadose Zone Soils

Efforts to characterize the distribution of carbon tetrachloride contamination in the vadose zone soils at the former CCC/USDA facility have been limited because of redevelopment of the property since 1974. The site of the former grain storage facility is now a housing development, and access for investigation is limited. Analyses of near-surface soils (approximately 0–4 ft BGL) from accessible locations on the former CCC/USDA property identified no carbon tetrachloride contamination above an analytical quantitation limit of 10 µg/kg (Argonne, 2005a). These findings indicate that no unacceptable health risks are associated with direct exposure to the near-surface soils at Murdock.

Investigations in 2004 targeted the identification of a soil-to-groundwater pathway in the area of the former CCC/USDA facility. Vertical soil and groundwater profiling identified such a contaminant pathway (Figure 2). Carbon tetrachloride concentrations up to 361 µg/kg were identified in subsurface soils at one location beneath the northern portion of the former CCC/USDA facility. Model simulations of potential leaching from the soils suggested that such carbon tetrachloride concentrations might continue to act as a dilute (< 23 µg/L) source of contamination to the underlying groundwater for at least 80 years (Argonne, 2003). At these source levels, however, the concentration of the carbon tetrachloride plume is expected to decrease continuously through natural attenuation or degradation, as in fact has been observed since 1991. The EPA considered the estimated time frame for natural attenuation of the contamination, as predicted from the model simulations, to be unacceptable and determined that a non-time-critical removal action is both appropriate for mitigation of the contamination at Murdock and warranted to protect human health and the environment.

Indoor air samples were collected in 1987–1988 and again in 2004 in several of the residences on the property previously occupied by the former CCC/USDA facility. Analysis of these samples indicated that no unacceptable health risks were associated with the potential intrusion of contaminated soil vapors into indoor air in the homes. On the basis of these studies, the CCC/USDA and the EPA concluded that no actions were necessary with regard to vapor intrusion.

Contamination in Groundwater

The carbon tetrachloride contamination in the groundwater at Murdock is restricted to a single aquifer that is laterally extensive beneath the town and the surrounding area. The aquifer at Murdock consists predominantly of glaciofluvial silts, sands, and gravels that reach a maximum thickness of approximately 50 ft, but thin locally due to erosional downcutting near the tributary creek and are absent beneath the recent silts and clays in the tributary bed. Periodic monitoring of groundwater levels at Murdock since 1991 has demonstrated a consistent pattern of groundwater flow from south to north-northwest across the site, with a focus toward the tributary creek. This pattern has controlled the migration of carbon tetrachloride contamination toward the tributary from the former CCC/USDA facility. Sampling and analysis since the early 1990s documented a decrease in maximum carbon tetrachloride concentrations in the groundwater plume from 7,800 μg/L in 1996– 1997 to 991 μg/L in spring 2004. Concentrations in excess of 350 μg/L persist, however, along much of the central axis of the current plume. The plume concentrations have decreased progressively through time as a consequence of natural degradation (Argonne, 2005a). The groundwater plume at Murdock is currently more than 3,000 ft long and 1,000 ft wide.

Contamination of Surface Waters and Groundwater Seepage

Groundwater discharge to the surface occurs in the headwaters area of the tributary creek northwest of the town, both as persistent springs and diffuse seepage along the creek banks and as outflow from a network of agricultural drain tile lines. Carbon tetrachloride levels detected in the surface waters along the tributary creek have generally increased since the original sampling in 1993. A maximum concentration of 281μg/L was identified at the headwaters of the tributary creek in spring 2004. Under Nebraska regulations, the maximum acceptable level of carbon tetrachloride in water discharged to the surface is 44.2μg/L. The observed concentrations in the surface waters of the tributary creek decline rapidly downstream. No carbon tetrachloride was detected beyond a point approximately 2,000 ft north of Waverly Road in the 2004 sampling.

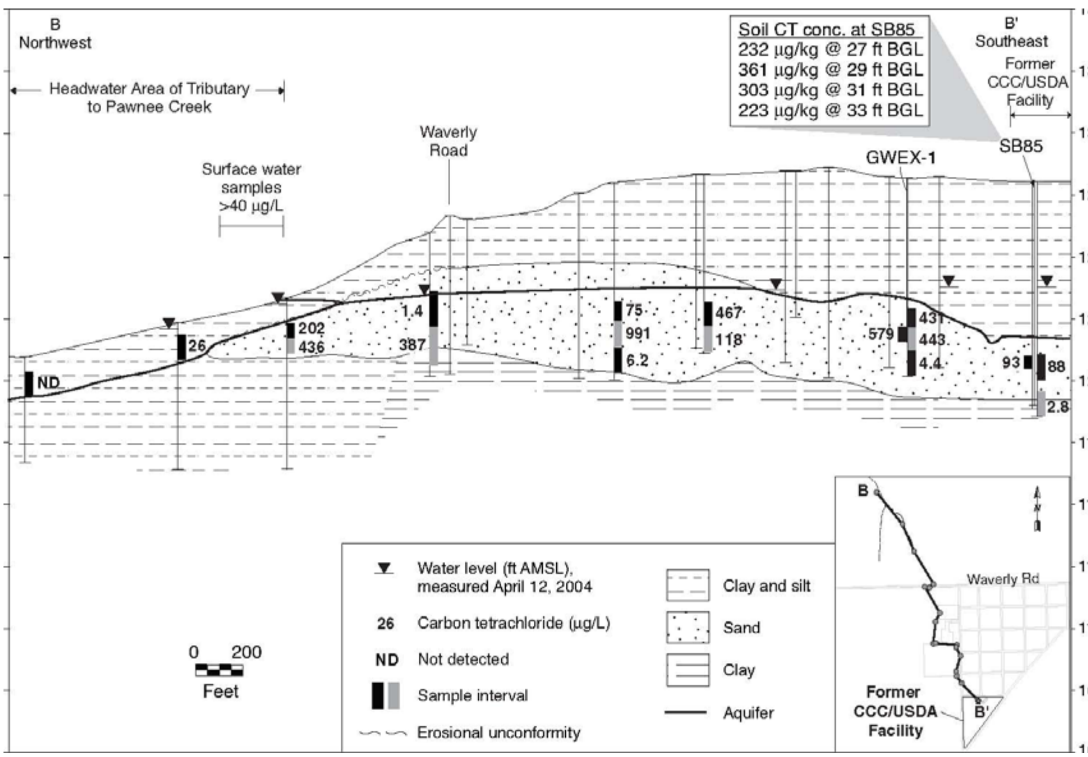


Figure 2. Vertical distribution of carbon tetrachloride in groundwater in the aquifer at Murdock (2004 data), displayed on an interpretive geologic cross section along the axis of the contaminant plume.

Integrated Remedial Approach

Prior to the recent investigations and modeling efforts, monitored natural attenuation (MNA) was accepted as a remediation alternative at Murdock. Under MNA, no *active* treatment measures are taken to decrease the toxicity, mobility, or volume of the existing carbon tetrachloride contamination in either groundwater or surface water. Reductions in the contaminant concentrations are predicted as a function of dilution, migration, dispersion, volatilization, and phytodegradation. More recently, the following three factors ruled out the continued acceptance of MNA as a feasible approach: (1) the time frame for cleanup of 80+ years (as derived from modeling), (2) the classification of the tributary of Pawnee Creek as an "impaired stream" by the Nebraska Department of Environmental Quality, and (3) the existence of an identified continuing source term with a defined soil-to-groundwater pathway emanating from the former CCC/USDA site (Figure 2).

A number of potential remedial technologies were investigated for their potential to meet the technical objectives for the site. No single, currently accepted approach was sufficient to address the complex, multi-faceted problem at Murdock. Furthermore, the CCC/USDA wished to apply innovative technologies beyond the commonly used pump-and-treat system to accomplish the remediation required. Consequently, a large-scale integrated remediation system was proposed and designed with the goals of enhancing remedial performance, reducing maintenance costs, and maximizing benefits to the local community.

The integrated-systems approach implemented at Murdock combines the following elements:

- Element 1 — Hot-spot hydraulic control involving extraction of groundwater and treatment with *a modified spray system* that irrigates recreational lands
- Element 2 — Interception of the carbon tetrachloride plume before the contaminated groundwater enters the creek through use of phytotechnologies (hydraulic control with phyto- and rhizo*degradation*), including use of deep-rooted trees planted in wells.
- Element 3 — Supplemental treatment by an *engineered wetland* immediately downgradient of the contaminated groundwater discharge zone.

Technical Objectives

The specific technical objectives of the integrated approach to remediation at Murdock are as follows:

- Hydraulically control any potential future contaminant migration in the groundwater originating from the former CCC/USDA facility
- Extract and treat contaminated groundwater from the central, concentrated portion of the plume

- Permanently decrease carbon tetrachloride concentrations in the groundwater and surface water at Murdock, thereby preventing further degradation of surface water and groundwater quality and restoring these resources for potential beneficial use
- Eliminate pathways for potential human exposure to carbon tetrachloride concentrations above the regulatory limits for this chemical in groundwater (5 μg/L) and surface water (44.2 μg/L)

Element 1 — Spray Irrigation System for Hot-Spot Control

Several years ago, Argonne conducted an extensive pilot study with a modified conventional agricultural spray irrigation system at Utica, Neb. (Argonne, 2000). The removal of volatile organic compounds (VOCs) from groundwater by spray irrigation had earlier been demonstrated by the University of Nebraska (Spalding and Burbach, 1994) and the EPA's Superfund Innovative Technology Program (Richardson and Sahle-Demessie, 1998) in experiments at the Hastings, Neb., Superfund site. Experimental results showed removal rates of up to 98% with center-pivot irrigation equipment under ideal conditions. Subsequently, full implementation of this technology at the Utica site resulted in a significant reduction in carbon tetrachloride levels in the groundwater (Argonne, 2005c).

Carbon tetrachloride levels in untreated groundwater from the extraction wells in the Utica plume ranged as high as 196 μg/L. Contaminated water was pumped from the aquifer by a series of extraction wells and treated by volatilization through the spray system. The remediated water was used to re-establish previously existing wetland basins that had been adversely affected by an extended drought and general lowering of water levels in the area. More than 13.4 million gallons of water were treated and discharged to the wetlands during the first 13 months of operation (Argonne, 2005c). The resulting improvement in habitat resulted in re-establishment of the wetlands of the North Lake Basin Wildlife Management Area, where a diverse community of flora and fauna now flourishes, and birds migrating along the Central U.S. Flyway find a resting place (Sedivy and Gilmore, 2004).

The CCC/USDA and Argonne postulated that a similar approach could be taken at Murdock. The centerline of the Murdock carbon tetrachloride plume, with the highest historical concentrations in groundwater, underlies the local school's athletic fields, directly downgradient from the former CCC/USDA facility (Figure 1). A smaller version of the Utica modified, spray irrigation system was developed and is currently withdrawing water from an extraction well drilled on the school grounds (GWEX-1) for this specific purpose (Figure 1). This extraction well pumps water from a highly contaminated part of the plume. The water enters the modified spray apparatus and is then applied in a light spray to the athletic fields. Since carbon tetrachloride is highly volatile, exposure of the fine mist to air and sunlight results in an almost immediate reduction in contaminant levels. Consequently, this system successfully treats an area of elevated carbon tetrachloride within the existing plume and captures some of the contaminant emanating from the source area. The result is a reduction in the overall contaminant levels in the plume moving toward the creek.

At Murdock, extracted water enters the spray irrigation system from the aquifer at contaminant levels of at least 131 μg/L; concentrations increase with continued pumping/extraction. Preliminary baseline testing indicated a maximum carbon tetrachloride concentration in the treated spray of 9.3 μg/L, with values averaging < 6 μg/L. A network of nearby monitoring wells indicated a radius of influence of the extraction well of at least 500 ft, with measurable drawdown observed in well 2D (Figure 1). Up to 2.5 million gallons of water will annually be extracted from the contaminated aquifer, treated, and used for irrigation by the Elmwood-Murdock public school (beneficial reuse). The school uses the spray system for watering athletic fields that were previously hardened and had little grass cover because of low historical rainfall in this area of Nebraska. The fields are now grass covered and more suitable for athletic pursuits. The risk of sports-related injuries has decreased markedly (Novak, 2005). This element of the integrated system has demonstrated that reuse of the water from the carbon tetrachloride plume is feasible and of considerable benefit to the community.

Element 2 — Phytoremediation Technologies

The mitigation of “hot-spot” contamination is inadequate to address the entire plume, particularly the portion that has already migrated toward the creek and beyond the sentinel wells along Waverly Road (Figure 1). Consequently, a technology was needed to deal with this portion of the plume. This second element to the integrated approach uses an engineered phytoremediation system in the downgradient, shallower part of the plume to achieve further mitigation of the groundwater contamination before the water enters the tributary to Pawnee Creek. Phytoremediation is the reduction of contaminant concentrations through use of plants, specifically trees and deep-rooted native prairie vegetation in this case. Phytoremediation is applied at Murdock to (1) augment current natural plant uptake of groundwater and entrained carbon tetrachloride, and (2) promote contaminant breakdown and prevent further degradation of surface water quality in the creek tributary.

The phytoremediation system implemented at the Murdock site was designed with the following elements:

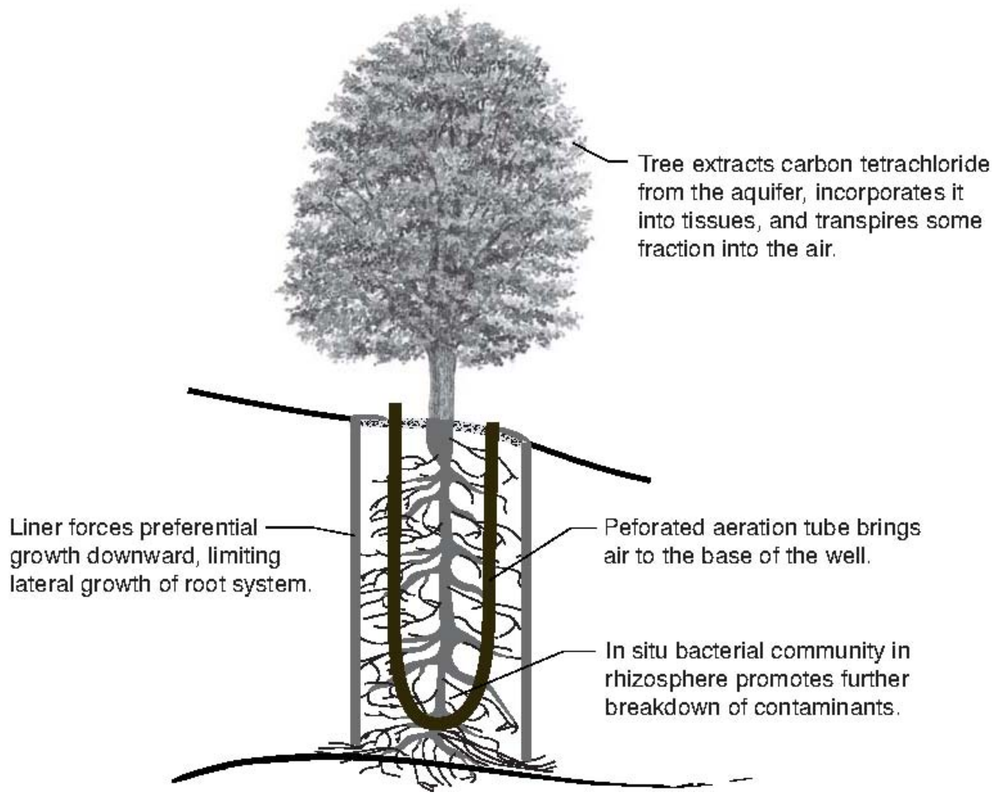
- Deep-rooting trees acting as individual pumps, selectively extracting groundwater from target zones in the contaminant plume and intercepting the contaminated groundwater at approximately 5–8 ft BGL, before it reaches the creek and it mixes with clean precipitation water
- A riparian buffer along the creek banks, preventing and retarding mixing of contaminated groundwater with uncontaminated surface water
- A surface vegetation cover (native prairie plants) using uncontaminated soil moisture in the vadose zone and preventing soil erosion
- A stabilized stream bank

Some 2000 trees belonging to six different species (Table 1) were selected for their rapid growth, deep rooting, disease tolerance, and non-opportunistic, non-weedy character. Established native vegetation already present along the banks of the tributary creek incorporates many of the same species and is also considered part of the remedial system.

To maximize chances of tree rooting at the target depths, a patented planting technique was used. The methodology, developed by Applied Natural Sciences, Inc. (http://www.treemediation.com/), involves use of “tree wells” to focus the growth of the root systems of the six species of trees selected (Figure 3). The tree wells were drilled with an auger to the level of the groundwater, in this case generally 5–8 ft BGL. The holes or wells were then lined to the same depth with a plastic liner that prevents the tree roots from expanding laterally and using more easily accessed moisture near the surface.

Table 1. Plant species in the phytoremediation plantation and wetlands at Murdock.

Trees	
green ash	*Fraxinus pennsylvanica* Marsh.
northern catalpa	*Catalpa speciosa* (Warcer)
weeping willow	*Salilx alba tristis cv* Niobe
black willow	*Salix nigra* Marsh.
eastern cottonwood	*Populus deltoids Bartr.Ex Marsh*. Souixland
hybrid poplar	*Populus x can. Robusta*
Grasses and groundcovers	
alfalfa	*Medicago sativa* L.
red clover	*Trifolium pretense* L.
Kansas big bluestem	*Andropogon gerardii* Vitman
Indian grass	*Sorghastrum nutans*
little bluestem	*Andropogon scoparius*
sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.
Virginia wildrye	*Elmus virginianus* L.
western wheatgrass	*Pascopyrum smithii* (Rydb.) A. Love
switchgrass	*Panicum virgatum* L.
Canada wildrye	*Elmus Canadensis* L.
Pond plants	
bullrush	*Scirpus californicus* (C.A. Mey.) Palla
arrowhead	*Sagittaria latifolia* Willd.
sedge	*Carex* L.
rush (zebra)	*Scirpus zebrinus*
spikerush	*Eleocharis interstincta*



Contaminated aquifer supplies water for tree's growth.

Figure 3. Tree well technology developed by Applied Natural Sciences, Inc., to focus growth of the roots of trees in the phytoremediation system.

The tree wells focus the growth of the roots downward toward the subsurface aquifer, which becomes the only readily obtainable source of water for the tree. Theoretically, the result is direct uptake of contaminated groundwater into the tree roots and tissues. The deep tree well planting technique was not applied along the banks of the creek, where the trees' access to groundwater was inevitable.

Element 3 — Engineered Wetland

Supplemental treatment is accomplished by an engineered wetland immediately downgradient of the zone where contaminated groundwater is discharged from the phytoremediation area.

The total volume of the wetland was based on the design normal pool elevation of 1,210 ft above mean sea level. The pool is just over 800 cubic yards or 0.5 acre-feet. The wetland achieves an average residence time of 4.2–11.8 days, on the basis of the total base flow rate (Ikenberry et al., 2006). The overall design incorporates an undulating bottom that increases residence time and adds to the biodiversity of the wetland. The normal operating depth varies from 0.5 ft to 2.5 ft as the water traverses the wetland. The design involves a meandering flow path that further increases residence time. The flow path of 390 ft has an average width of 60 ft. This configuration results in a length:width ratio of 6.5:1. Most guidance for design of constructed wetlands suggests a ratio of at least 4:1.

The plants introduced into the new wetlands area for habitat restoration and improvement are listed in Table 1.

Computer Flow and Transport Modeling

To meet treatment goals, the systematic design process involved determination of design parameters; simulation of existing surface water runoff, evapotranspiration from the various vegetation types, groundwater flow, and contaminant transport; and selection of appropriate vegetation species and components for the engineered phytoremediation system and constructed wetland. Consequently, throughout system design, the remedial systems were integrated to (1) minimize interference from clean surface water and infiltrating soil water, while optimizing direct uptake of contaminated groundwater by the phytoremediation system; (2) exploit multiple treatment effects by reducing the hot-spot contaminant concentration and coupling the phytoremediation system with the supplemental wetland treatment system; (3) meet requirements for low maintenance; and (4) maximize benefits to the ecosystem and local community.

Extensive groundwater modeling formed the basis for the decision to attempt an integrated system. A flow model was constructed in 1993 to simulate the flow system in support of initial simulations of groundwater flow beneath the former CCC/USDA property. Initial model simulations suggested that natural attenuation of the carbon tetrachloride plume would occur in a 15-year time frame. Monitoring continued, and data accumulated in 1993–2000 indicated that a much longer time frame would be required than the original estimate of 15 years. Recalibration and updating of the original steady-state groundwater flow models (MODFLOW-2000) indicated that a period in excess of 80 years might be required to achieve restoration of the contaminated groundwater under MNA (Argonne, 2003). The results indicated the existence of a continuing soil source/source term of carbon tetrachloride in the vadose zone beneath the former CCC/USDA facility. An investigation in 2004 targeted current conditions in the groundwater and surface water in the vicinity of the tributary creek. Revised mass transport models were constructed to simulate the distribution of carbon tetrachloride as measured in 2004 (Argonne, 2005a). These simulation results formed the basis for constraining, developing, and evaluating the phytoremedial design that eventually became a reality at the Murdock site.

To identify optimal conditions for implementation of each element of the proposed integrated remediation approach, coupled models of groundwater flow and contaminant transport were used to quantitatively simulate the response of the groundwater and surface water systems under various groundwater pumping and vegetation planting scenarios. Two separate groundwater flow–contaminant transport model pairs were used to represent the critical characteristics of the site. Each pair of models was constructed, calibrated, and tested through use of site-specific sampling, monitoring, and hydrogeologic data, plus climatic, water balance, and plant metabolic data for the local area. In each case, groundwater flow was simulated by using MODFLOW-2000, an enhanced version of the well-documented and validated MODFLOW finite-difference modeling code developed by McDonald and Harbaugh (1988). Carbon tetrachloride transport was simulated by using the modular, finite-difference solute transport code MT3D-MS (Zhang and Wang, 1998).

To simulate the relatively large-scale features of groundwater flow and contaminant transport at the site, coupled flow-transport models were constructed to represent an area of approximately 1.3 square miles around the town and the headwaters of the creek, with minimum areal resolution of 50 ft _ 50 ft for the finite-difference grid spacing.

A sequence of 12 model layers represented the vertical distribution of the aquifer hydraulic properties and carbon tetrachloride contamination in the predominantly thicker portion of the groundwater system in this area.

A second coupled groundwater flow-contaminant transport model pair was developed to address the more detailed features of groundwater flow and carbon tetrachloride migration near the creek tributary. In this pair, the minimum areal discretization was 10 ft _ 10 ft, and the thinner vertical hydrostratigraphic sequence was represented by three layers for flow and four layers for transport. These models were specifically constructed to permit the simulation of phytoremediation options near the creek and account for the natural "pumping" action associated with plant uptake of groundwater from the shallow aquifer near the tributary.

The large-scale and smaller area models were constructed and calibrated separately. However, they were linked in that the groundwater flow characteristics and the contaminant concentrations simulated with the large-scale models for the approximate (downgradient) location of Waverly Road were used to constrain the (upgradient) boundary conditions at Waverly Road imposed on the smaller area models.

The groundwater modeling simulations indicated that maturation of approximately 1,800 trees planted along the margins of the tributary (where contaminated groundwater has been discharged) will result in (1) significant cones of depression and hence zones of groundwater and contaminant capture and (2) a decrease of approximately 90% in groundwater flow. In addition, seasonal pumping of a groundwater extraction well near the Murdock school (with beneficial reuse of the water for irrigation of the adjacent school property) will capture contaminated groundwater from the upgradient portion of the plume and hydraulically contain any carbon tetrachloride contamination originating in the future from the subsurface soils at the former CCC/USDA facility (Argonne, 2005b).

Simulations of hydraulic control effected by the phytoremediation plantation indicate a maximum drawdown of 3-4 ft in the water table locally. This estimate was particularly important in consideration of a water budget in relation to the local agricultural activities. Figure 4 presents simulations of both the present-day plume configuration and the inferred removal and containment of the carbon tetrachloride plume north of Waverly Road, 10 years after maturation of the trees in the phytoremediation system.

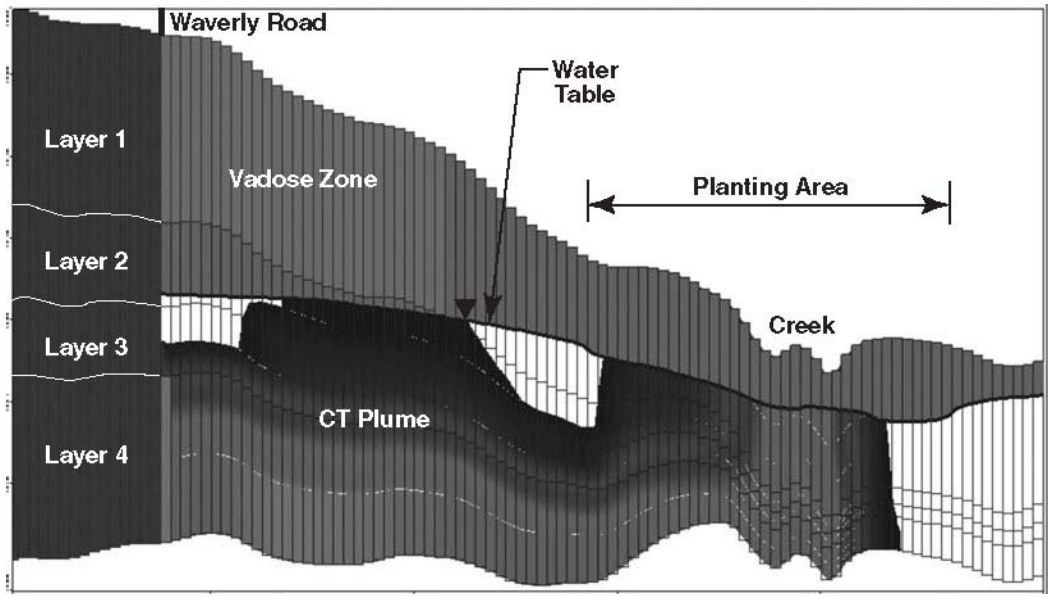


Figure 4. Simulation results for the present plume configuration and for inferred contaminant removal and containment north of Waverly Road, 10 years after maturation of the trees in the phytoremediation system.

System Monitoring Program

Monitoring Plan

Restoration of both the groundwater and surface water at Murdock will be a lengthy process. In the initial five-year period, the spray irrigation system, phytoplantation, and constructed wetland are expected to become well established and to reach their full potential as critical elements in the remediation system. An intense five-year sampling and monitoring program to document the effectiveness of the overall system has begun with a baseline study. Monitoring during this initial period will provide data that will become the basis for appropriate modifications to maximize the remedial potential of the system. The objectives of the initial five-year monitoring period are as follows:

- Monitor the spray irrigation system.

  Conduct quarterly sampling of the treated groundwater spray.

  Use data on cumulative groundwater production and spray sampling results to estimate the quantities of carbon tetrachloride and chloroform removed from the aquifer.

Evaluate the spray system's effectiveness relative to the target concentration of 4.2 µg/L.

- Monitor the phytoremediation system.

  With water level recorders, make hourly measurements in a network of 16 observation points to observe diurnal fluctuation and quantify hydraulic "pumping" effects. Results will assist in determining groundwater withdrawal rates by the trees, as well as in management of the local water budget.

  Collect and analyze tissue and leaf samples from the trees and deep-rooting grasses in the plantation area. Accumulation of carbon tetrachloride in the plant tissues will verify contaminant removal by the phytoremediation system. Additional parameters for tree growth, such as annual increment of tree height and leaf size,will be monitored to ensure continuing remedial function of the system.

  Collect groundwater samples for geochemical analyses to monitor for reducing/anaerobic conditions required for enhanced microbial degradation of carbon tetrachloride (reductive dechlorination) in the rhizosphere. Directly measure microbial activity and removal of carbon tetrachloride from the system.

- Monitor for carbon tetrachloride daughter products.
- Monitor surface water treatment systems.

  Collect surface water samples in a series of critical locations along the tributary creek for VOCs analyses, to evaluate the effectiveness of the overall integrated system.

- Monitor contaminant reduction in the groundwater plume.

  Collect groundwater samples semi-annually at selected points along the central axis of the existing plume and in the monitoring wells throughout the phytoremediation area for VOCs analyses. Results will provide evidence of systematic reduction in contaminant levels.

- Monitor local atmospheric carbon tetrachloride levels.

Twice yearly, collect air samples for VOCs analyses along the public pathways to ensure that human exposure levels remain within acceptable limits. Baseline sampling in the phytoremediation area found no contamination, despite the presence of carbon tetrachloride in the tissues of nearby existing vegetation, but release of carbon tetrachloride to the atmosphere is expected to increase in both in the phytoremediation and wetlands areas as these systems become established during the initial five-year period.

Baseline Sampling Studies

An initial event to collect samples for VOCs analyses was conducted at Murdock in July 2005, shortly after the groundwater extraction system was installed and the main phytoremediation areas were planted. This sampling was performed to (1) provide a current "snapshot" of the carbon-tetrachloride distribution in the previously identified groundwater plume and surface waters at the headwaters of the tributary creek, and (2) establish baseline data for future comparisons that will permit evaluation of the performance of the remedial systems implemented at the site and progress toward restoration of the Murdock aquifer.

The July 2005 sampling activities included (1) groundwater and surface water sampling throughout the area affected by the carbon tetrachloride plume, (2) tissue sampling of the newly planted vegetation in the phytoremediation area, and (3) ambient air sampling in the planted and preexisting vegetated areas along the tributary creek. Results of these analyses are summarized below.

Groundwater Analysis Results

To determine current levels of carbon tetrachloride contamination in the upgradient portion of the groundwater plume, groundwater samples for VOCs analyses were collected in July 2005 at nine permanent observation locations along and south of Waverly Road (Figure 5). These observation points were installed during previous work at Murdock to facilitate periodic sampling along both the approximate central axis of the identified groundwater plume and near its lateral margins. At each location, a cluster of two or more borings provides vertical resolution of the contaminant distribution within the plume.

To complement and extend the pre-existing monitoring network, new permanent observation wells were installed at nine locations near the headwaters of the tributary creek north of Waverly Road, both in and adjacent to the phytoremediation planting area (Figure 5). Four well clusters were installed along a linear trend roughly following the central path of groundwater flow and contaminant migration toward the tributary creek. Four additional wells are located on an approximate transect across the contaminant plume, in the area where groundwater discharge to the creek has consistently been observed. A final well is located near the identified downgradient erosional limit of the Murdock aquifer (Argonne, 2005a).

The general configuration of the carbon tetrachloride plume in July 2005 (Figure 6) is consistent with measurements made in 2002 and 2004 (Argonne, 2005a). The 2005 data, however, provide a more detailed picture of the carbon tetrachloride distribution in the headwaters area of the tributary creek. Concentrations of carbon tetrachloride above 1,000 μg/L were detected at two monitoring wells along the axis of the carbon tetrachloride plume, indicating that highly elevated levels of the contaminant are now approaching the phytoremediation planting area.

Two additional groundwater samples were collected from within the root systems at two of the deep tree-planting locations (Figure 6), through vertical ventilation tubes installed for root aeration in each of the tree wells. Detection of carbon tetrachloride in one tree well suggests that some uptake of contaminated groundwater began before baseline sampling. The high ratio of chloroform to carbon tetrachloride (31 μg/L versus 38 μg/L, respectively) at this location suggests that some degradation of carbon tetrachloride also preceded the baseline sampling.

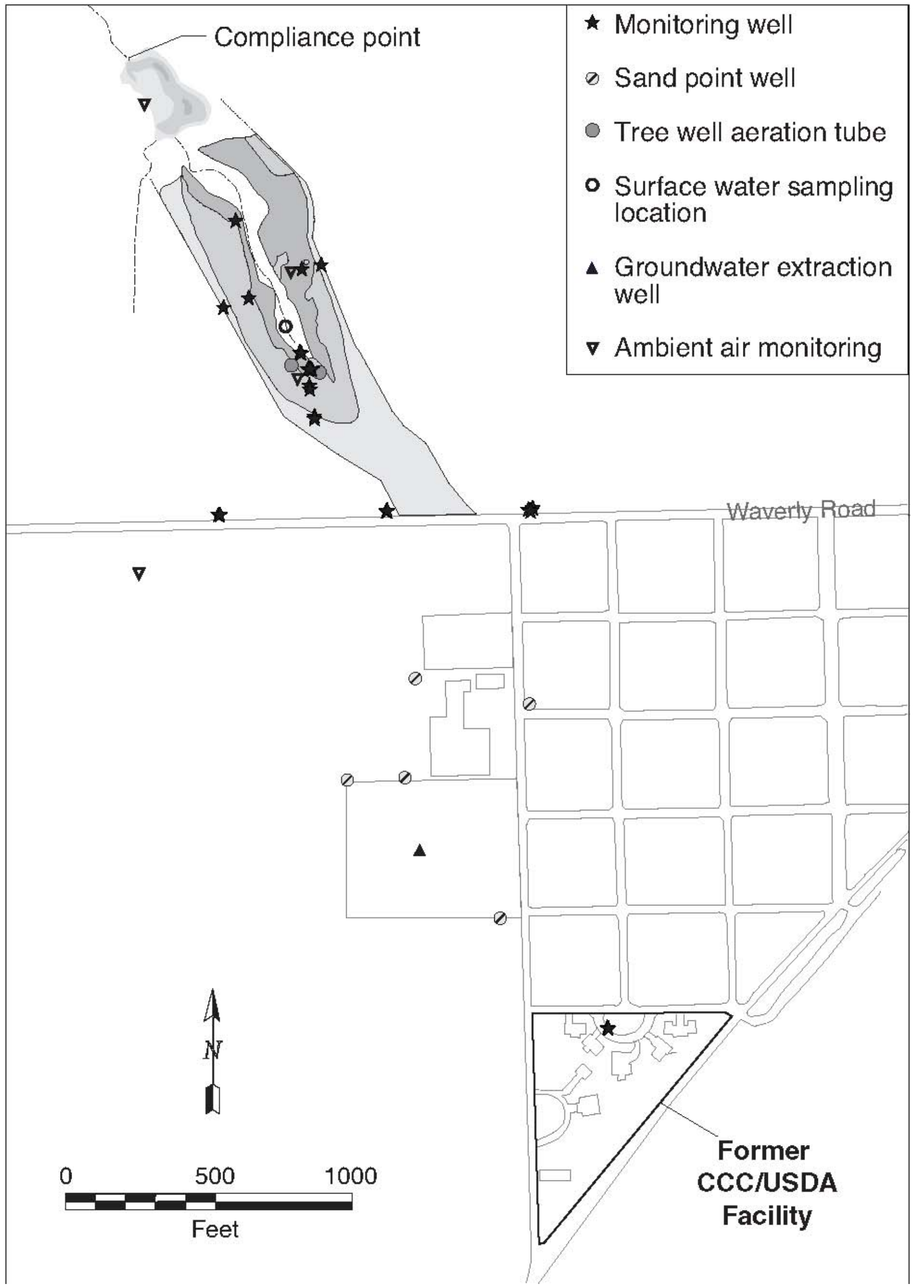


Figure 5. Locations for monitoring of the Murdock treatment systems.

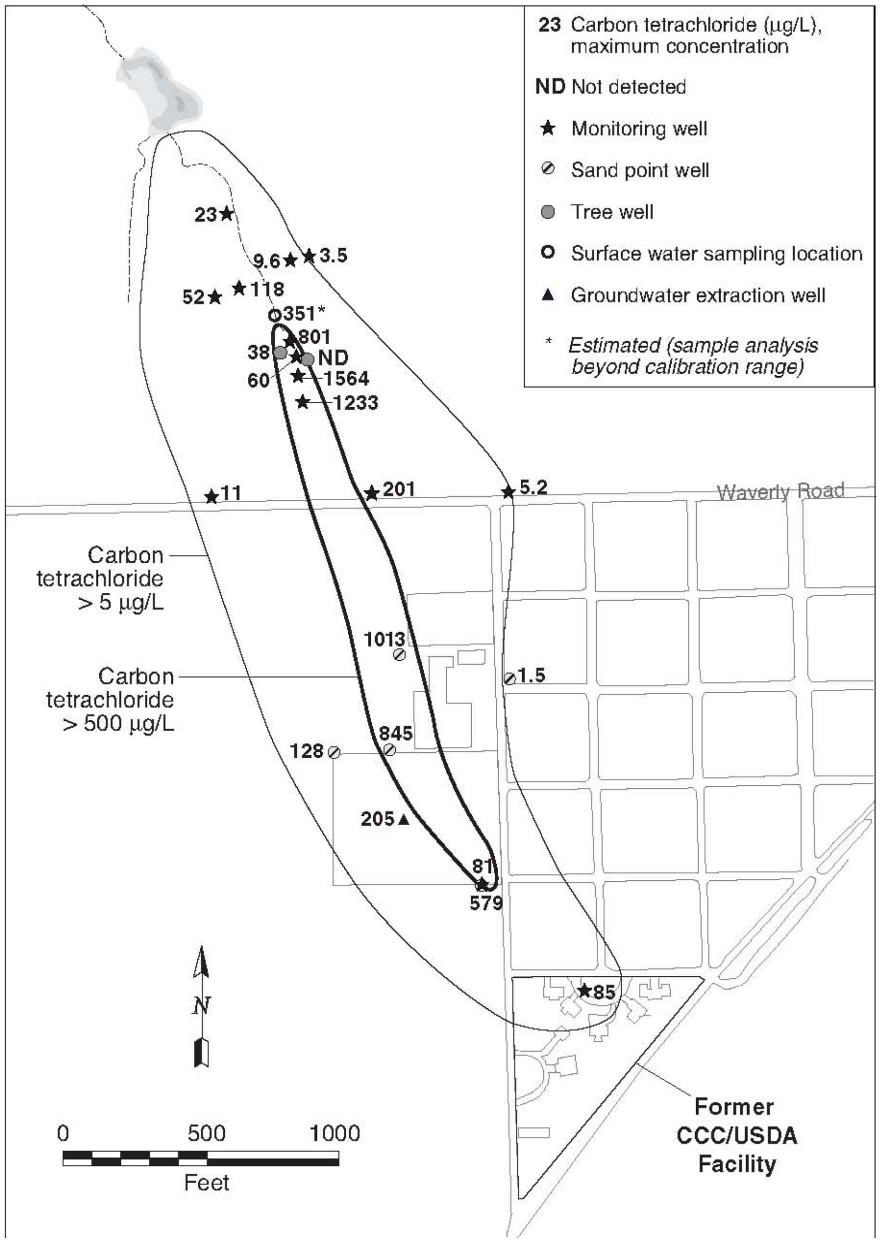


Figure 6. Summary of analytical results for VOCs in groundwater and surface water samples collected in the July 2005 baseline monitoring of the Murdock treatment systems.

Surface Water Analysis Results

One surface water sample was collected in July 2005 (Figure 6). The estimated carbon tetrachloride concentration for this sample (351 μg/L) was similar to levels detected at this location in 2004 (Argonne, 2005a). Earlier periodic sampling at this location consistently identified this location as the approximate point of maximum carbon tetrachloride discharge (on the basis of measured concentrations) to the surface waters of the tributary creek.

Plant Tissue Analysis Results

The vegetation planted in the phytoremediation area at Murdock is expected to take up, transpire, and degrade carbon tetrachloride as the plants take root and mature. Previous sampling of preexisting natural vegetation along the tributary creek indicated that these processes should result in elevated levels of carbon tetrachloride in plant tissues, reflecting elevated levels in the groundwater. Leaf and branch samples were collected in September 2004 from selected mature, very well established willow, ash, and mulberry trees along the banks near the headwaters of the creek to assess the potential for success of this approach. Concentrations of carbon tetrachloride in branch tissue samples were up to 530 μg/kg in the willows and a surprising 750 μg/kg in ash trees. In addition, the presence of chloroform in the same tissue samples suggested ongoing carbon tetrachloride degradation in plant tissue (Argonne, 2005b).

To obtain baseline data for the phytoremediation plantings, plant tissue samples were collected from new trees in the phytoremediation area several times during the summer and fall of 2005 and analyzed for VOCs. The vegetation sampling included all six species of trees incorporated in the new plantings. Sampling occurred in every other row, at every fourth or fifth tree in the sampled row. Background samples were collected at two nearby locations that have not been affected by the groundwater plume. Samples of branches and leaves collected in July 2005 were analyzed by a headspace technique based on a modification of EPA Method 5021-1 (http://www.epa.gov/epahome/index/). Maximum carbon tetrachloride concentrations identified at each location in July 2005 (Argonne, 2006) are summarized in Figure 7.

A total of 206 plant tissue samples were collected in July 2005 at 102 locations in the shallow and deep planting zones. Insignificant headspace concentrations of carbon tetrachloride (< 1 µg/kg) were found in most of the tissue samples during this initial baseline sampling. The results indicated, however, that some uptake of contaminated groundwater had already occurred at the time of sampling (by Niobe willows) at six locations in the surface planting zone. The detected carbon tetrachloride concentrations at these locations were generally low (< 4 µg/kg). The only exception was a concentration of 43.2 µg/kg at one location (Figure 7).

During the same sampling event, 12 plant tissue samples were collected at six locations in two uncontaminated "background" sites near the phytoremediation area: (1) along the western branch of the tributary creek and (2) at a private residence along Waverly Road, east of the plume migration pathway. No carbon tetrachloride was found in these samples. Headspace concentrations of chloroform ranged from < 1 µg/kg to 3.1 µg/kg, reflecting apparently ubiquitous low levels of chloroform in the natural vegetation in the vicinity of the tributary creek headwaters (Argonne, 2006).

Subsequent, a smaller scale sampling of trees in September 2005 was conducted to confirm the July 2005 results and determine if a pattern of uptake by trees could be detected. Results of this more limited, targeted study confirmed the July detections with the finding of increased contaminant levels in the same trees, and tissues in neighboring trees also showed detectable levels of carbon tetrachloride and chloroform. These results demonstrate that as rooting occurs in the soil, trees are establishing a pathway to take up contaminated water and influence the site hydrology.

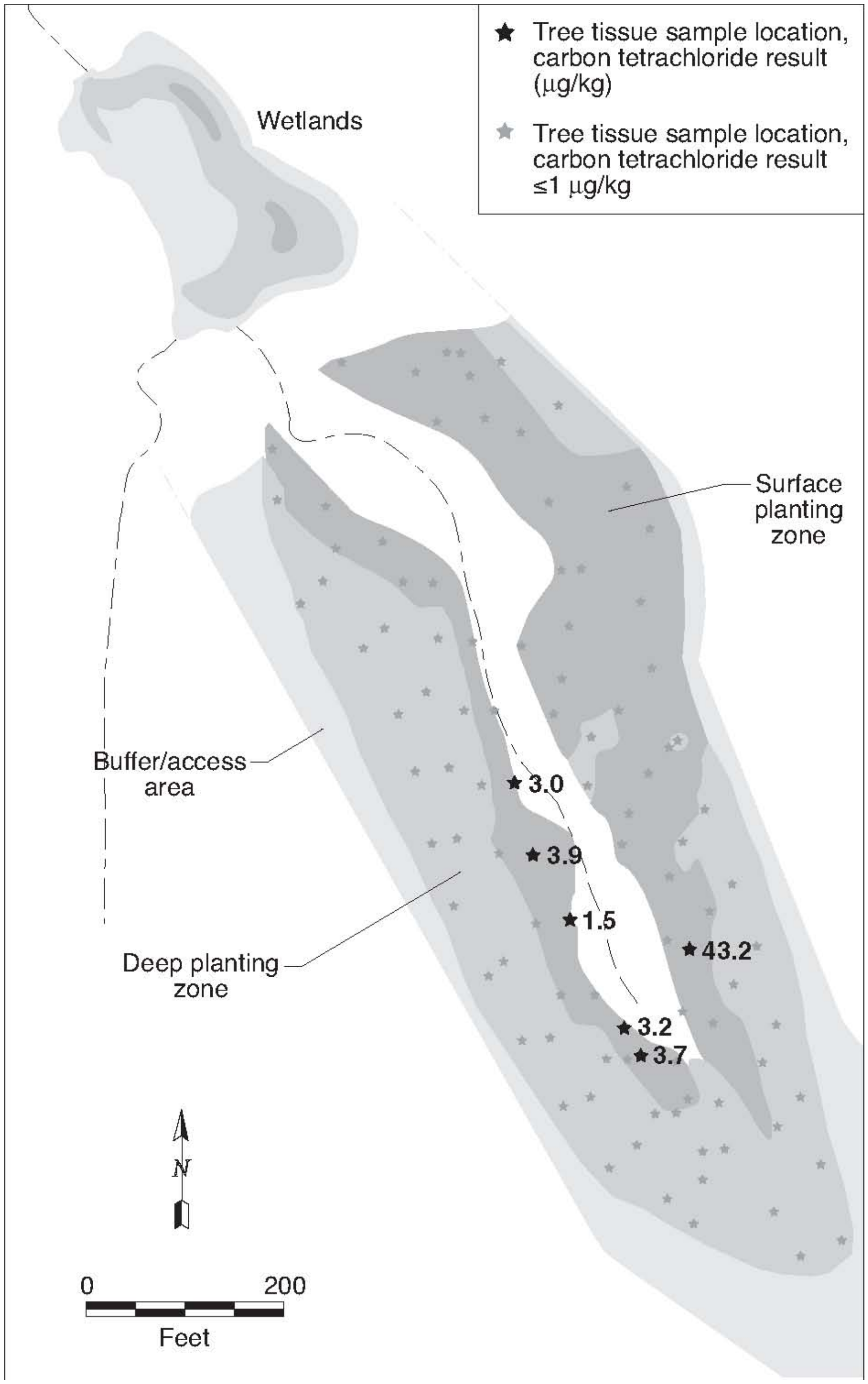


Figure 7 Results of analyses for carbon tetrachloride (maximum values) in vegetation samples collected in the surface and deep phytoremediation planting zones during the July 2005 baseline sampling at Murdock.

Ambient Air Analysis Results

The most persistent concern expressed by members of the local community is the potential health effects of close proximity to a large number of trees actively transpiring carbon tetrachloride into the atmosphere, particularly for individuals walking on the pathways along the planted area. The EPA recommended the Agency for Toxic Substances and Disease Registry's intermediate inhalation minimal risk level of 0.03 ppm or 192 $\mu g/m^3$ (ATSDR, 2006c) as a conservative target concentration for carbon tetrachloride in ambient outdoor air (EPA, 2005). To measure carbon tetrachloride concentrations under ambient air conditions in 4-hr increments for several days, pre-evacuated air-sampling canisters were placed within the tree canopy among the newly planted trees (Figure 5). In this baseline testing, carbon tetrachloride was found at the detection limit of 1.3 $\mu g/m^3$ at only one location on one of the three days in the sampling period, at a position corresponding to the location of an identified high level of carbon tetrachloride in branch tissue of mature trees. Chloroform was not detected.

Baseline Stable Isotope Studies

Stable isotope ratio measurements of groundwater, dissolved carbon tetrachloride, and plant tissues from mature and newly planted trees were made to document baseline conditions (Sturchio and Gonzalez-Meler, 2006) at Murdock. These initial studies indicated that the processes affecting the fate and transport of carbon tetrachloride can be assessed, and future changes can be documented. Stable isotope results are extremely sensitive to changes in water balance, evaporation, microbial degradation of carbon tetrachloride, and water stress in the trees of the phytoremediation zone. Initial results at Murdock indicate little variation in isotope ratios of hydrogen and oxygen in groundwater across the site and suggest values near those of mean annual precipitation. Carbon and chlorine isotope ratios of dissolved carbon tetrachloride are similar in most portions of the plume, although variations along the flow path suggest significant evaporation and microbial degradation in the vadose zone at the head of the plume. Carbon isotope ratios of mature trees along the plume indicate root access to groundwater. The isotope results provide a useful baseline against which to measure future changes in the fate and transport of carbon tetrachloride, as well as access of newly planted trees to groundwater.

Long-Term Sampling and Monitoring

At the conclusion of the initial five-year period, the integrated remediation system will be critically evaluated to accomplish the following:

- Establish long-term performance monitoring procedures.
- Evaluate progress to date and the potential for the system to achieve ultimate restoration of the groundwater resource at Murdock.
- Identify and implement modifications to the various system elements that will improve the performance of the integrated system.

Conclusions

Results of the baseline sampling in July 2005, shortly after completion of all elements of the Murdock remedial system, indicate that the intended outcome of the integrated remedial approach designed for the site is achievable. The following critical observations can be made, even at this early date: (1) the extraction-spray irrigation system is decreasing contaminant concentrations to acceptable levels, exerting its influence over a radius of 500 ft, and improving the quality of the school athletic fields;
(2) highly contaminated water in the groundwater plume is approaching the phytoremediation plantation; (3) carbon tetrachloride is accumulating in newly planted tree tissues in certain areas; (4) the trees are establishing a pathway for uptake of contaminated groundwater and are influencing site hydrology; (5) contaminant levels in surface water have not changed significantly; and (6) carbon tetrachloride is barely detectable in ambient air at canopy level among the newly planted trees. These initial observations indicate that the remediation systems have the ability to meet and exceed expectations, even very early in the treatment process. Implementation of the regulator-approved monitoring plan will generate additional data as treatment continues.

Acknowledgements

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INSECTICIDE CHOICE FOR ALFALFA MAY PROTECT WATER QUALITY

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Abstract
Some insecticides used for controlling Egyptian alfalfa weevil have been detected in California's surface waters and are of concern due to their impact on water quality and toxicity to some aquatic life. To assess the impact of insecticide choice on water quality, we collected tail-water samples from on-farm alfalfa sites in the Sacramento Valley over a three-year period. Samples were collected during irrigation after organophosphate and pyrethroid sprays had been applied. We found significant differences between insecticide classes on the mortality of *Ceriodaphnia dubia* (water flea), a test organism used to detect pesticides in water. Nearly all sites where organophosphates were used resulted in 100% water flea mortality in a 24-hr test of tail-water samples; pyrethroid-treated sections of the same fields exhibited insignificant water flea mortality. Although pyrethroids can move off site attached to soil particles, lower sediment levels were found in irrigation tail water than source water. Pyrethroids were not detected in alfalfa tail-water samples to a detection limit of 50 ppm. The pyrethroids used provided significantly better control of weevils than the organophosphates, with no significant differences in beneficial insect counts. Although water runoff does not always occur in alfalfa fields, insecticide choice may be an important tool for protecting water quality.

Key words: water quality, pesticides, alfalfa, weevils

SAVING AMERICAN FARMS FROM EXTINCTION ONE FARM AT A TIME

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Abstract

American farms are becoming part of a bygone era. Thousands of farm acres are disappearing as alternative land uses become more profitable than farming. Animal farms face issues of waste removal, air pollution, toxins, and excess nutrients leaching/runoff; and salination of soils- all of which add regulations and increased costs to the farmer. This presentation discusses two enhanced bio-remediation technologies. The first tackles and solves most of these problems in a natural and environmentally beneficial manner and is called "green lagoon technology." It liquefies solids and sludge, eliminating agitating costs and time; changes lagoons from anaerobic to aerobic states; eliminates odors and flies; and provides an enhanced manure fertilizer effluent 80% taken up by the crops building a humus soil base, leaving little to leach into or run off the soil. The second, "salt detoxification," creates agents that act as a "buffer" for plants. This buffering effect allows soil microorganisms to proliferate, protecting them from harmful osmotic pressures. These conditioners inhibit salt uptake by the plant by a chelating effect, making them less susceptible to salt damage. Collected data from a series of 2005/2006 studies in Minnesota and North Dakota will be presented.

Key words: remediation, lagoon, dairies, manure, nutrients

Manure Remediation: A Mandate for U.S. Farms

World agribusiness faces unprecedented opportunities and challenges over the coming decades. The current world population stands at more than 6.6 billion, increasing at more than 1.4% per year. This leads to a 33% gain, more than 8.8 billion, in the next 20 years. Additionally, urbanization and improved living standards in many developing nations are increasing the per capita demand for symbols of this new lifestyle; namely, increased consumption of meat, fish, and dairy products. In countries where food supply from animal sources has historically been low, consistent increases in these products in the diets of children have resulted in marked improvements in growth, cognitive development, and health, due to the higher availability of essential amino acids, minerals, and vitamins (Melvin, 2003; Horrigan, 2002).

Because of this positive change, demand for animal-based agriculture products, including meat, poultry, dairy, etc. will be growing at a rate substantially greater than the projected population growth alone. While the agricultural industry has demonstrated significant growth in productivity over the past 25 years, meeting increased demands during that period has exacted a considerable price.

That price can be seen in increased water and air pollution from excess salts, nutrients, pesticides, antibiotics, volatile compounds, and other contaminants. Sadly, this price is only going to escalate during the next 25 years. According to the EPA, more than half the U.S. streams and rivers are polluted, with 52% of the streams in the Eastern U.S. rated as "poor." Current unchecked farming practices are responsible for upwards to 70% of this pollution. Improperly managed manure alone has caused serious water quality problems throughout the U.S (Horrigan, 2002; U.S. EPA, 2003).

Problems associated with manure are not disappearing. As more animal production is accomplished by concentrated animal feeding operations (CAFO's) and to improve productivity, the scale of the manure problem increases dramatically in the region surrounding the CAFO.

A 1997 USDA survey (Ribaudo, 2003) showed that the largest CAFOs (more than 1000 beef/dairy, 2500 hogs, or 100,000 poultry) represented only 6% of the farms, but in themselves generated more than 65% of the excess nitrogen/phosphorous nutrients in soil and groundwater. Today the percentage of large operations has increased substantially from the data in 1997.

Today's U.S. farmer has to cope with an ever-growing tide of federal, state, and local regulations; animal diseases; weather and environmental conditions; overseas competition; and neighborhood complaints while simultaneously trying to achieve a reasonable return on his substantial investment. The farmer understands the ramifications of poor manure management practices but has not had feasible solutions for solving these increasing problems.

Manure solutions, to date, have universally been ineffective, limited in scope, or beyond reasonable economic application. U.S. and foreign academic communities have proposed a plethora of concepts and ideas, but none have found general acceptance for most of the farmer's problems (Jacobson). The American Public Health Association has even proposed a moratorium on new CAFOs until all uncertainties are resolved (Osterberg, 2004).

Currently, the most common approach for handling manure from CAFOs is to transfer it to a containment area, commonly called a lagoon or pit on the farm property, and then to pump it onto local crops or truck it to nearby farms. This pumping process normally occurs once or twice a year depending on the size of the lagoon or pit and the number of animals in the CAFO. Three sets of issues have an effect on manure-handling decisions. These are (a) volume of liquids and solids, (b) odor, and (c) groundwater contamination issues. All of these are also affected by the specific weather conditions around the CAFO, and each of them influences the other two.

In brief, as a lagoon/pit is filled by the manure liquids and solids (plus rain, sawdust, sand, urine, etc.), the solids tend to solidify and settle on the bottom. When the manure is pumped, this sludge must be broken up by mechanical or hydraulic agitating allowing it to flow out with the liquid. Over time, most lagoons build a permanent deep layer of sludge that is too firm to be removed by agitation.

Since all untreated lagoons are anaerobic in nature, this hardened layer sometimes helps keep odors contained beneath the surface crust, realistically only a temporary containment, which will remain only as long as the acid-forming and methane-forming bacteria are in balance. However, this growing layer of sludge creates two large problems.

First, it uses effective lagoon space, reducing the time required between pumping events. Second, the odor associated with it during agitation is usually onerous. To regain lagoon capacity, it becomes necessary to mechanically dredge the lagoon, which is costly and has the potential of damaging lagoon liners on floors or walls.

Many studies have been performed on the components of odors and the dispersion properties of those compounds, and many recommendations for reducing odors (e.g. covers, anaerobic digestion, biofilters, etc.) have been offered. These odor-causing compounds include ammonia, hydrogen sulfide, mercaptans, aldehydes, ketones, amines, p-cresol, indole, etc. These mainly occur due to the degradation of the organic waste material under anaerobic (sufficient negative oxidation reduction potential) conditions. It is generally accepted that odors do not present problems if aerobic conditions predominate in a lagoon (Jacobson; Schmidt, 1998; Baumgartner, 1998).

Contamination of groundwater occurs both from leakage from the lagoons as well as the spreading of raw manure onto crop acreage. Components of this pollution range from excess nitrogen and phosphorous applied to a ground area (more than the crops can uptake) to the specific incorporation of pathogens (fecal coliform, cryptosporidium, E-coli, etc.), heavy metals, grease, salt compounds, feed additives, and other organics in the manure. These contaminants can then either leach into the local groundwater or be carried in runoff to local streams and watercourses. The high nitrogen content in raw manure degrades into nitrites and eventually to nitrates, a known carcinogen.

GreenFlash Technologies (GFT) has developed and demonstrated a new biological technology for manure storage facilities that addresses many of the challenges facing today's animal production farm. This technology, called green lagoon (GL) is a biological remediation approach that goes beyond any known existing biological techniques, yet is economically advantageous to both large and small CAFOs as well as commercial animal producers.

Table 1 provides a summary of the performance characteristics of the GL process and an identification of the specific parameters measured in recent demonstrations at four dairy farms in Minnesota. While the GL technology addresses some aspects of all three of the manure problem areas, these tests focused on performance of the technology on lagoon volume and odors while operating under the harsh conditions of a Minnesota winter.

GL addresses contaminant issues by various approaches. While GL does not increase or decrease the total amount of nitrogen or phosphorous in the manure, it uses advanced chelating techniques to build humus in the manure to contain or bind the nutrients in the plant root zone and to significantly increase the percentage of nutrients that can be taken up by the crops. Certain pathogens (e.g., coliform-based) are reduced or eliminated by the action of the GL microbials in out-competing the pathogenic bacteria for their required food source. Salts and heavy metals (e.g. arsenic) are buffered or encapsulated by the unique chelation properties of the GL technology, such that they remain in manure but are unable to affect the soil or water environment, effectively detoxifying these contaminants.

Odors are reduced or eliminated by microbial action, which converts the lagoon/pit from anaerobic to aerobic without the need for expensive aeration equipment or the inclusion of other entities, such as algae or chemicals. This is the result of GL microbes metabolizing the carbon atoms in the manure, which releases water vapor and carbon dioxide. Residual oxygen ions remain in the lagoon, creating the aerobic condition. In the Minnesota tests, the aerobic nature of the lagoons was demonstrated by specific measures of dissolved oxygen (DO) in the lagoons (ranging from 0.15 mg/L to 4.0 mg/L) at the end of the treatment period. Odor reduction was attested to by independent observers in the field (including pumpers, neighbors, etc.).

Volume issues are addressed directly. The deep sludge layers are metabolized by microbial action and liquefied. They are then pumped out with the other liquid components of the lagoon. In the demonstrations recently completed, volume improvements were enormous. In one farm, the operator estimated an increase of four feet of capacity across a two-acre lagoon; in another farm (see Figure 1), a large sludge island built up over many years collapsed into the lagoon as its underpinnings were liquefied.

Results and pictures of the actual lagoons were taken, along with data (by independent laboratories) demonstrating the change from anaerobic conditions to aerobic conditions. Observations on all of the conditions were provided by the farm operators. A key point to remember is that the large majority of the test period was throughout the winter months when biological solutions other than those of GL become dormant.

Figure 1. Lagoon showing sludge island before treatment and after collapse into the bottom of the lagoon.

Table 1. GL Technology applied to major lagoon issues.

	Designed to Handle	Measured in Latest Demo	Proven in Earlier Tests	Comments
Volume Issues				
Hardened Sludge	YES	**YES**		Liquefied by microbial action, i.e. .metabolizing of the carbon atoms
Solid Manure	YES	**YES**		
Urine/Urea	YES	**YES**		Hydrolysis and microbial action on urea molecule
Sand	NO			
Sawdust	YES	**YES**		Degraded by microbial action, i.e. metabolizing of the carbon atoms
Metallics	NO			
Odor Issues				*Odors significantly degraded*
Oxygen Depletion	YES	**YES**		Changes lagoon from anaerobic to aerobic; greatly increases DO counts
Odors / Volatiles				Odors significantly degraded through the action of specifically cultured odor degrading bacteria
Ammonia	YES	**YES**		Degraded by hydrolysis and microbial action
Hydrogen Sulfide	YES	**YES**		Lagoon changes to aerobic state; degraded by microbial action
Volatile organic compounds	YES	**YES**		Chemical binding of odor-causing molecules, and degrading by microbial action of specifically cultured odor degrading microbials
Volatile Fatty Acids	YES	**YES**		
Aldehydes	YES	**YES**		
Mercaptans	YES	NO		
Ketones	YES	**YES**		
Groundwater Issues				
Excess Nutrients	YES	NO	YES	Proprietary chelating properties contain within (bind) root zone and increase percentage uptake by plants
Organic Material	SOME	NO	YES	Stimulates aerobic decomposition of stubble, crop, and other organic residues into humus
Salt Compounds	YES	NO	YES	Buffers (encapsulates) sodium compounds
Grease	YES	NO	YES	Degraded by metabolizing of the carbon atom
Pathogens				
Fecal coliform	YES	NO	YES	GL bacteria out-compete for the nutrient food source of Coliform bacteria, substantially weakening and/or eliminating them (9)
Escherichia coli	YES	NO	***	
Heavy Metals	YES	NO	YES	Buffers (encapsulates) many heavy metal compounds
Hormones	NO			Never tested
Antibiotics	NO			Never tested
				*** Not directly proven, can be inferred from fecal coliform results
Weather Conditions				
Cold Temperatures	YES	**YES**		Products contain proprietary microbes with temperature characteristics beyond those of other natural microbes.
Warm Temperatures	YES	NO	YES	

Salt Detoxification; Salt Contamination and Bio-Complex Buffering©

The environmental contamination of the greatest number of acres of farmland in the U.S. is caused not by toxic chemicals or oil spills but by salt. More than 23% of irrigable land in the U.S. is now salt-impacted, and the number grows every year. In the California San Joaquin Valley alone, more than 2.8 million tons of salt enter the valley each year, and only 350,000 tons leave it. Worldwide, the problem is estimated at more than 20% of all irrigable lands being salt-impacted.

When soil is damaged by salt contamination, the harm extends immediately to native grasses, trees, shrubs, and crops, preventing seed germination and plant growth. Saline conditions also destroy favorable microorganisms vital to productive, balanced soil. Soil contamination is most prevalent in two main areas of environmental concern: agricultural irrigation/fertilization and oil production. In most cases, crop irrigation is pumped from underground aquifers that contain high amounts of soluble salts. When land is irrigated with this water, large amounts of salt accumulate on the surface. If salts are not leached adequately, there will be significant damage to plant roots.

Both chemical and natural animal fertilizers contain high amounts of salt. When farmers use fertilizers to increase production, they magnify the problem. The excessive “doses” of salt from these fertilizers cause salt content in the soil to continually increase. Farmers find they have to use more and more fertilizers to produce less and less crop yields, and salt levels steadily increase. Eventually the crops will be destroyed or production greatly reduced unless something is done to prevent, break down, or “buffer” the existing salt buildup.

The salt "breakdown" process works as follows:

- Salt is a metal and very reactive. Excessive salt amounts act as a toxin to aerobic soil microorganisms that require oxygen to establish their colonies and metabolize nutrients.
- Salt follows the water path and can be flushed from the soil. However, extensive flushing of salt into the soil with water only temporarily corrects the problem. It has not solved the problems which result from high soil salinity.

Using GFT's bioremediation and soil "balancing" products to recondition soil will enhance microbial growth by producing and converting organic materials into agents that will combine with salts. These agents act as a "buffer" for the plants. This buffering effect allows soil microorganisms to proliferate, protecting them from harmful osmotic pressures. These conditioners inhibit salt uptake by the plant by a chelating effect, making them less susceptible to salt damage.

A significant salt contamination problem also occurs in oil production fields. As with irrigation, oil pumped from injection wells contains an exceptional amount of saline water. When oil transmission lines rupture, the damage has a two-fold effect. Not only will the leak's salt content contaminate the surrounding soil, the leak also contains hydrocarbons that will destroy native flora, fauna, and indigenous microorganisms.

While state and federal regulatory agencies enforce the cleanup of hydrocarbon contamination, until recently cleaning up salt problems was not considered economically feasible. Flushing with water didn't provide a permanent solution and there were no additional alternatives. After any such salt contamination, the land usually is written off as being unable to support plants.

Salt damage to soil cannot be ignored. Consumer liability is beginning to play a role. For instance, if a transmission line leaks on land that is used for cattle grazing or farming, the owner likely will demand the cleanup of the land. Using bioremediation for transmission line leaks will alleviate both the salt and the hydrocarbon damage.

The GFT agricultural line includes an assortment of salt "buffering" products which will not only buffer any salt contamination but will return salt-contaminated land to a rich and productive soil, which will then support all types of crops. All of this occurs at a reasonable price and in a timely manner.

There are products that buffer salts through soil application (irrigation or spraying on soil), while others are formulated for foliar (leaf) application. They are "leaf friendly." GFT foliar products are organically complexed and salt-buffered to ensure maximum uptake and translocation. This reduces the occurrence of leaf burn or phytotoxicity.

Plants have differing levels of tolerance to the salinity in the soil. As a general rule, higher-value fruit and vegetable crops are relatively salt intolerant, while forage and field crops have a somewhat higher tolerance. A few examples are given below.

Crop Salinity Tolerance

Crop	Ec(0)	Ec(25)
Wheatgrass	7.5	11.0
Soybean	5.0	6.2
Flax	1.7	3.8
Corn	1.7	3.8
Lettuce	1.3	3.2
Oranges	1.7	3.2
Plums	1.5	2.9
Strawberries	1.0	1.8

In this table, salt tolerance is given in terms of electric conductivity, where Ec(0) represents the maximum salinity a crop can handle without suffering yield decreases (in mmhos/cm), and Ec(25) is the point where a 25% yield decrease occurs and the crop's economics becomes questionable.

In spring 2006 experiments in North Dakota, a variety of crops were grown on a field whose salinity had an Ec of 16.9._Photos of the field, before and after, are below. This field was treated with GFT SaltDetox, starting about one month before planting.

Before GFT Salt Detox-treatment
Photo taken March, 2006

After GFT Salt Detox-treatment
Photo taken July, 2006

Additional Information

The video shot during the August 8, 2006, oral presentation can be viewed on the Web site of GreenFlash Technologies at www.greenflashtech.com. Go to the main page; click on Videos, scroll to **"**The Future of Agriculture – Sacramento**,"** and click.

Also on the page is the PowerPoint presentation used during the oral presentation.

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DISSOLVED ORGANIC MATTER FLUXES, QUALITY, AND REACTIVITY IN RUNOFF FROM AN AGRICULTURAL WATERSHED IN THE CENTRAL VALLEY, CALIFORNIA

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Abstract

Elevated concentrations of dissolved organic carbon (DOC) in surface waters are a significant concern in California because of the potential formation of carcinogenic disinfection by-products during drinking water treatment. Here we will present data on surface water DOC quantity, quality, and reactivity during 2005 and 2006 from a 425-km^2 agriculturally dominated watershed in the Central Valley of California. Surface water DOC concentrations range from approximately 2-6 mg/L at the mouth of the watershed during baseflow, up to approximately 10 mg/L during winter storm events. Changes in DOC quality are indicated both spatially and temporally by optical characterization (UV absorbance and fluorescence), and likely reflect changes in the sources and flowpaths of surface runoff. Preliminary data on specific trihalomethane formation potential (a DBP) suggests that reactivity of DOC to chlorination also varies both spatially (e.g., grassland headwaters versus watershed mouth) and temporally (storm events versus baseflow periods). The relative role of particulate organic matter fluxes and fluxes of other forms of dissolved organic matter (nitrogen and phosphorus) will also be discussed, along with implications for watershed management and drinking water quality.

Key words: watershed, dissolved organic carbon, agriculture, water quality, disinfection by-products

BUILDING PARTNERSHIPS FOR RESTORATION IN A WORKING LANDSCAPE: THE LOWER MOKELUMNE RIVER WATERSHED STEWARDSHIP PROGRAM, CENTRAL CALIFORNIA

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Abstract
Stakeholder cooperation is essential for development and implementation of restoration within a watershed composed primarily of agriculture. In order to enhance watershed health, a large and diverse group of local stakeholders in the lower Mokelumne River Watershed, central California, effectively collaborated to complete the Lower Mokelumne River Watershed Stewardship Plan in 2002. Ten elements are addressed in the plan, including restoration. The restoration element emphasizes protection, enhancement, and/or restoration of riparian habitat that will simultaneously serve to reduce stream bank erosion; stabilize levees; provide a buffer or transition zone between the river and agricultural operations; reduce occurrence of non-native invasive plant species; and increase habitat values for anadromous fish, riparian birds, and terrestrial wildlife. The plan is now in the planning, prioritization, and implementation phase with 50 landowners within the watershed demonstrating a commitment to protect, restore, and/or enhance approximately 800 acres of riparian habitat. Commitments range from evaluating and planning restoration/enhancement opportunities, to implementing funded projects. We will discuss the process of building partnerships between private landowners and government agencies that leads to successful collaboration within the context of the plan. Examples of current planning, restoration, enhancement, conservation, and monitoring projects will also be discussed.

Key words: collaboration, stewardship, agriculture, restoration, watershed management

A CROSS-SECTIONAL SURVEY OF CALIFORNIA'S GRAZED RANGELAND RIPAIRAN AREAS.

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Abstract

Significant concern exists about grazing impacts on riparian resources. Scientific literature shows that improper, and often undefined, grazing leads to negative impacts on riparian resources. Unfortunately, the literature does not provide a toolbox of field-tested, practical grazing management recommendations to safeguard riparian resources. We conducted a survey of rangeland riparian areas across California, collecting data allowing identification of sites by management combinations correlated with high and low riparian health scores. Data on more than 130 variables was collected at each site and can be grouped as health assessment scores, site characterization variables, and management variables. Data was analyzed using backward step-wise GLM and was done for three levels of classification. The final model derived for Level 1 was health assessment score = 15.732 – 0.248(stock density) – 0.332(frequency) + 0.003(rest between grazing) + 0.024(herding) + 0.046(OA time) + 0.111(frequency*stock density), n= 128, R^2= 0.20. As site characteristics are taken into consideration, we obtain a final model for mountain meadow streams as health assessment score= 13.846 + 0.007(rest between grazing) + 0.043(herding) + 0.088(OA time), n= 67, R^2= 0.24. Natural variance between stream types is removed, allowing managers to choose management practices associated with enhancing the type of streams they graze.

Key words: riparian, grazing, habitat, management

Introduction

Theresa Becchetti presented initial results of research aimed at establishing an interaction between cattle grazing, riparian habitat, and fisheries. Riparian grazing strategies and their impact on riparian health has been a focus of researchers for many years. In the late 1990s, reviews of the literature were conducted (Allen-Diaz et al., 1999; Belsky et al., 1999; Larsen et al., 1998; Rhinne, 1999), noting critical study components had been left undefined such as the stocking rates, physical characteristics, and the grazing system utilized for previous research. The experiments tended to compare "grazing" to "no grazing", a scheme that does not provide enough information for land managers to make well-informed decisions. Researchers also noticed that there was sparse information pertaining to direct links between grazing and adjacent fisheries, an important relationship. In sum, the preceding literature seemed to be lacking a toolbox of tested, site-specific grazing recommendations for land managers to utilize. Therefore, instead of using small plots, the current research identified the need to look at the landscape through a data-driven, management-scale project with the goal of identifying feasible grazing management strategies that ultimately can be utilized by land managers to enhance and safeguard riparian resources.

Objectives were many-fold, with the first to complete a cross-sectional survey of California's rangeland riparian areas. Next, researchers sought to identify grazing management practices and site characteristics associated with high and low "riparian health scores." Researches synthesized the data for site-specific recommendations, and are publishing and extending the information gathered. Finally, a subset of the sites was utilized to develop a set of case studies for long-term monitoring.

Study sites were established throughout California from north to south, and were concentrated in the Sierra Nevada foothills, and coast range of the state, with no sites on the Central Valley floor. Assessments were done while streams were flowing for intermittent and ephemeral streams.

Three visual assessment worksheets were utilized as survey tools, two habitat-driven with one developed by the EPA (Barbour et al., 1999) and the other by NRCS (Natural Resources Conservation Service, 1998); and one based on hydrologic conditions, developed by the BLM (Prichard et al., 1998). Researchers also put together a site-characterization worksheet characterizing different components that could potentially pertain to various site-specific details; the goal of the worksheet was to get as site specific as possible. Researchers also utilized a 130-question management survey that aims to gather as much information as possible from managers about the site, its history, and present use.

The two habitat-driven assessments from the EPA and NRCS both utilized similar characteristics, such as presence of large woody debris, undercut banks, condition of gravel and cobbles on the stream bottom, and pools, to rate the sites on a numeric scale (1 to 20 and 1 to 10, respectively). The BLM's worksheet was more concerned with hydrologic function than with habitat features. For example, whether the creek has become too wide and shallow without proper flow or whether the creek has become entrenched without access to its traditional floodplain were questions utilized to assess the health of a system. The site-characterization worksheet recorded such important physical details as width and depth of creek; flow; bank-full width and depth; and dominant vegetation, which included the top four species present in the riparian area as well as the adjacent upland. Two hundred twenty-one grazed sites were evaluated utilizing 25 habitat questions, 17 hydrologic function questions, 65-site characterization covariates, and 130 management questions to tease out exactly what has been going on in the pasture or allotment. Approximately 100 ungrazed sites were also evaluated.

A Pearson correlation was used to compare the NRCS, EPA, and BLM assessments. The EPA and NRCS assessments correlated well yielding an r-value of 0.81. This was expected as they utilize similar visual habitat characteristics. The BLM assessment was not nearly as well correlated with either the NRCS or EPA assessments. This result was also expected, since the BLM assessment focuses on hydrologic function, while the other two are more concerned with habitat. Therefore, researchers decided to omit the NRCS worksheet and solely utilized the final outcome score from the EPA assessment and the BLM designation.

Researchers also determined which out of 65 covariates recorded had a significant impact on the outcome of habitat scores, using general linear regression. Entrenchment, substrate and percentage canopy were the covariates found to be significantly related with the final rating of all three habitat assessments used in the study. Rosgen stream morphology (Rosgen, 1996.) components were utilized as the first-cut, site-specific covariate, since this system captures some of the most important variables when classifying streams that were found to be significant across all three assessments, such as entrenchment ratio for level I streams and the substrate size parameter pertaining to level II streams in the Rosgen system.

The Rosgen system classifies streams with a letter designation A through G. A-streams have limited flood plains and tend to be found in the mountains and foothills; B-streams are similar but with easier access to floodplains. C and E-streams tend to be found in mountain meadows, and have large floodplains and many meanders. G-streams are degraded, and F-streams are degraded, but rebuilding. To determine how best to obtain site-specific results, EPA habitat scores were compared to Rosgen stream classifications. A, B, C, and E-streams that are considered healthy and stable systems under the Rosgen classification were significantly different from and scored higher with the EPA assessment than the F and G-streams considered unhealthy under the Rosgen system. As a result, the Rosgen classification was utilized as a covariate to reduce variation between sites and obtain site-specific results.

Current management practices (such as person days per year) were examined at increasing levels of detail. At the most inclusive, least-site-specific level I analysis, all 128 grazed sites, with completed management surveys, were included in the data set. From there, the data set was divided based on whether the site was a perennial system with a summer growing season in the mountains or annual grasslands in the foothills with a winter growing season for the level II analysis. Finally, those two data subsets were each further divided into another two data subsets based on the Rosgen stream classification type.

For the most exclusive, site-specific level III analysis, A and B-streams were clumped together since they were very similar and not significantly different from each other to predict an EPA outcome score. They were separated from C and E-streams which were also very similar and not significantly different. Since this part of the analysis was to identify grazing management associated with enhancing riparian health, F and G streams were omitted from analysis since in most cases management had been changed since the stream became degraded. Further analysis will be done on those sites in the future.

A- and B-streams were characterized by steep gradients, a limited floodplain, bedrock and boulders, and containing limited herbaceous vegetation. C and E-streams, on the other hand, were characterized by a limited gradient (.5-1% slopes), large floodplains, and many meanders; such streams are typical of mountain meadow systems with much more herbaceous vegetation and access for livestock compared with A and B-streams.

Out of 130 management survey questions, researchers selected questions that seemed most relevant to yield management practices managers could utilize in their toolboxes. The most important of these independent variables were: growing season grazing (early, late, or entire season, dormant season), stock density (number of head per acre), animal unit per acre per year (no. of animals/acre/year), rest provided (yes/no)
rest between grazing (days), frequency (number of times per year pasture is grazed), herding (man days per year), off-site attractant provided (yes/no), off-site attractant time (man days

per year), and fencing (yes/no). Backward-stepwise general linear regression was utilized to determine management practices significantly associated with habitat outcome (EPA), and a two-tailed test was utilized to determine significant management practices for predicting BLM assessments completed only for level III final models.

Results from the level I analysis showed habitat scores were negatively associated with increased stock density and increased grazing frequency. The level I analysis also yielded results illustrating habitat scores were positively associated with more rest between grazing, more herding, and more time spent utilizing off-site attractants.As noted earlier, the level II analysis is somewhat more site-specific, with less variation between sites. The level II analysis pertaining to summer-growing mountain systems illustrated habitat scores positively associated with more rest between grazing, more herding, and more time spent utilizing off-site attractants. The level II analysis pertaining to winter-growing annual grassland systems illustrated habitat scores negatively associated with higher stock density. The difference between data subsets is likely a consequence of foothill pastures tending to be smaller in acreage than mountain pasture allotments and contain different types of riparian systems.

The level III analysis was the most site-specific analysis. In the case of the summer-growing A and B-stream sites, the sample size of eight was too small to draw conclusions; the minimum sample size for this study was set at 20. Summer-growing C and E-streams, on the other hand, yielded results similar to the level II analysis, but the relationships were stronger, as the level of analysis was more site-specific. For these sites, habitat score was positively associated with more rest between grazing, more herding, and increased time spent utilizing off-site attractants. The model demonstrates common management practices safeguard riparian resources. A logistic two-tailed t-test was performed to see whether the aforementioned management practices were also positively associated with a higher BLM hydraulic-functioning rating. The statistics showed that herding, but neither rest between grazing nor time spent on off-site attractants, was significant in determining the outcome of the BLM hydraulic-functioning rating. However, use of off-site attractants was demonstrated to be significant in determining the BLM hydraulic function rating.

In the case of the level III analysis pertaining to winter-growing, foothill systems with A and B-streams, no variables were significantly associated with higher habitat scores. This makes sense because these streams tend to have more exposed rock and little herbaceous cover, and are therefore more resistant to impact of cattle. Winter growing season, foothill systems with C or E-streams demonstrated that habitat scores are negatively associated with increased stock density; however, this variable was not significant predictive of hydraulic function rating. It is intuitive that increased stock density would be negatively associated with higher habitat scores in these systems.

To demonstrate the importance of examining similar sites, the relationship between a common management practice and the habitat outcome score can be examined across the three levels. Time spent providing off-site attractants was found to be significant across all three levels of analysis. Furthermore, as site-specificity increased so did correlation coefficients and R-squared values. As a result, the research demonstrates managers can receive "more bang for their buck" when recommendations are as site-specific as possible and treat each pasture as an individual rather than simply looking at averages.

In conclusion, underlying factors interact with management regimes requiring us to provide more site-specific recommendations to properly evaluate the effectiveness of management practices. The Rosgen system captures the majority of variation within and between streams, allowing stream classification to be what guides site-specific research and recommendations. However, researchers are identifying grazing management practices that can be associated with higher habitat scores. Simple management practices such as herding can have a positive impact on riparian health.

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TRACK 4
ENVIRONMENTAL MANAGEMENT SYSTEMS

PRODUCER-LED EMS INITIATIVES DRIVE THE NEED FOR NEW POLICY

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Abstract
Four panel members provide a summary and overview of recent environmental management system (EMS) initiatives in agriculture undertaken in dairy, livestock, row-crop, and wine-grape producer settings. Johnson facilitated the development of the first EMS in Wisconsin dairy based on the ISO 14001:2004 standard. Johnson will comment on how Wisconsin's Green Tier law provides incentives for EMS adoption. A certified ISO 14001 auditor, Johnson will provide perspective on the role of certification in producer-led EMS initiatives, and the need for policy mechanisms to drive EMS design and implementation. Harrison will address the challenges of developing organizations to facilitate producer-led, peer-learning networks on EMS and the need for federal, state, private, and philanthropic resources to advance environmental management among producers. Wolf, leading a multi-component EMS project with producer-members of the Iowa Soybean Association, will comment on the experiences of monitoring, measuring, and validating performance on the EMS continuum, and how this is the most likely way for farmers to capture value on input management while also addressing non-point source pollution. Ohmart will report on the earned value of crafting a certification standard and the development of an eco-label. The session will explore the challenges and roles for producers, trade associations, USDA, EPA, NRCS, crop consultants, extension, and others interested in EMS, certification, and eco-labeling in agriculture.

Key words: environmental management systems, input management, non-point source, environmental management, environmental performance, conservation programs

FERTIGATION TRAINING: BEYOND SYSTEM UNFORMITY

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Abstract
Growers are faced with the change of making sure their use of nutrient is efficient and sound. In the hands-on training workshops we offer, we emphasize the concepts of irrigation distribution uniformity (DU) and fertilizer uniformity. We emphasize that DU is a prerequisite for efficient fertigation, but irrigators have to go beyond this step. By using fertilizer travel time, injection time and flush time of irrigation lines, they can provide their plant with uniform and effective fertilization without causing degradation to the environment.

Key words: fertigation, distribution uniformity, flush time, injection time, travel time

Introduction

For decades, farmers and irrigators have practiced the science of fertigation, the injection of fertilizer through irrigation. With the advent and wide adoption of drip irrigation, this practice gained wider acceptance. Drip fertigation supplies nutrients directly to the roots of the plant and offers the ability to spoon feed them at a rate that closely follows their pattern of nutrient uptake.

In California's central coast, the majority of vegetable crops are irrigated and fertilized using drip irrigation. These irrigation systems are well managed with good distribution infirmity. However, with increasing environmental concerns and resulting regulatory pressures to manage nutrient pollution, it became clear that irrigation distribution uniformity (DU) alone, while critical, is it not enough to ensure good nutrient management and certainly will not compensate for poor fertigation strategies.

Irrigation distribution uniformity

Obtaining an even distribution of nutrients using fertigation can be challenging on the central coast. Growers are often managing many small fields with different shapes and sizes that are located at varying distances from where fertilizer is injected into the irrigation system. They may not know how much time is needed for the injected fertilizer to travel through the irrigation system. Many growers practice short, frequent water applications and fertigation, a practice that may not allow for complete flushing of the system. In addition, there are growers who have fields with poor irrigation uniformity that translates into poor fertigation results. In our outreach effort, we developed and continue to deliver a series of hands-on training workshops that use a demonstration drip system to teach the principles of drip irrigation and fertigation to growers, foremen, and irrigators. In these workshops, we focus on the importance of the two concepts of proper irrigation and fertilizer injection.

Good water management starts with a good uniform irrigation system. This concept is conveyed via hands-on exercises to evaluate system uniformity. Training attendees carry out pressure balancing of the demonstration system to detect friction losses or plugged emitters. They used pressure gauges and Schrader valves affixed to drip tape ends.

Afterward, they carry out an evaluation of outflow by collecting discharges for emitters at different locations in the field. The discharge rate of the tape is measured by collecting water during a 10-minute period from individual emitters at locations that represent the head, middle, tail, and sides of the field or irrigation block.

The collected water data is then used to calculate a DU value. The distribution uniformity can be calculated from these data by computing the ratio of the lowest quarter average and that of all the volumes measured collected during the exercise, according to the following equation:

$$distribution\,uniformity\,of\;lowest\,quarter = \frac{average\;of\;lowest\,25\%\;of\;volumes\;measured}{average\;of\;all\,volumes\;measured}$$

Afterward, the participants engage in a discussion of the data, how it relates to DU, and what corrective measures they can take if DU values are low. Once the DU is determined and is brought up to a desirable level (equal or greater than 85%), then we conduct the fertilizer injection exercise.

Fertilizer distribution uniformity

Discussion of the second phase of the hands-on workshop focuses on two topics, fertilizer use and even nutrient distribution. We discuss fertilizer types and review the appropriate fertilizer materials suitable for injection. This segment also covers possible incompatibilities of different products and how to perform a simple test prior to injection to avoid the formation of precipitates which can plug the emitter. Finally, we discuss fertilizer quantities to use and their correlation to plant growth stages.

The demonstration prototype is set in two sub-blocks, simulating two irrigation blocks on a farm. Each block is set up to inject at a different injection rate (1X and 2X). The goal is to compare the effects of fast and slow injections on fertilizer travel time. A concentrated solution of dissolved nitrogen fertilizer and food-grade dye is injected at contrasting rates in each block. Participants collect water discharged from the emitters in cups at locations that represent the head, middle, tail, and sides of the field. A timekeeper notes down the time the dye was first observed at each location in the field. The time required for the dye to reach the furthest point of block is equal to the travel time of the fertilizer.

At the end of the slow injection, the participants replace their cup with an empty second cup. The second cup is removed when clear water is collected for a period of time equal in length of the travel time. This represents flush time. Participants compare all the paired cups by contrasting color intensity and by reading electrical conductivity values of the water. The following observations and conclusions were discussed with workshop participants at the conclusion of the exercise:

- The injected dye traveled at a rate that was dependent on the flow of water in the drip tape and not on the rate of injection.
- The injected fertilizer travels rapidly at the head of the field but then moves progressively slower towards the tail end of the field.

These two observations illustrate the concept of travel time, the time span it takes injected fertilizer to reach the farthest point in the field. Travel time is independent of the rate of fertilizer injection. This is because fertilizer moves at a speed dictated by speed of water movement in the drip lines. Emitter discharge rate lateral lines will determine the speed of water in the drip tape. As water approaches the end of the tape, there are fewer emitters providing flow and, subsequently, lower flow rates in this region of the tape.

- As flush time approaches or exceeds travel time, fertilizer distribution in the field improved dramatically.

- For both rates of injection, the fertilizer was poorly distributed when flush time was shorter than travel time.

Flush time is the time it takes to clean the lateral lines of any injected material. Flush time is correlated to travel time. When lateral lines are cleaned for a time equal or greater than travel time, participants observed equal distribution of fertilizer as indicated by color intensity in the discharged liquid in the cups. EC readings in different cups also supported this observation. Collected discharged solution during travel time only (cup one) resulted in intense color and higher EC levels (0.74 – 0.82 mmohs/cm) at the front-end of the field. Water collected from the tail end of the field was almost clear, and the EC was close to background level of the irrigation water (0.4 – 0.44 mmohs/cm). Collected solutions during flushing alone (cup 2) reversed the trend and ranged from 0.44 mmohs/com at the front of the field to more than 0.80 mmohs/cm at the tail end. However, the overall cup average EC of the combined travel/flush times (cups 1 and 2) was around 0.66 mmohs/cm.

The third concept that was demonstrated is that of injection time. Attendees observed that whenever injection time was shorter than travel time, fertilizer distribution was less than satisfactory.

When injection time, travel time, and flush time were all equal, relative fertilizer distribution was improved.

The principal derived from this discussion can be summarized bythe following recommendations. After injecting, irrigators should allow enough time to flush the system completely of fertilizer. Conversely, the worst thing an irrigator can do when fertigating is to shut off the system when the fertilizer tank is empty.

However, flush time should be at least one to two times longer than the travel time, so as not to exceed the critical point beyond which mobile nutrients, such as nitrates, would leach beyond the root zone and eventually pollute groundwater.

Conclusions

Fertigation is a very useful tool for applying nutrients to drip-irrigated crops if steps are taken to ensure that the distribution is uniform. The hands-on sessions emphasize two principal concepts, irrigation uniformity as expressed by distribution uniformity (DU) and fertilizer distribution in the field.

DU can be assessed indirectly via pressure readings at the head and tail end of the field, or directly by collecting water discharges from emitters at different points in the field. High DU of 85% or more is required to effectively utilize fertigation.

To successfully achieve fertilizer distribution uniformity, growers need more than just a uniform delivery system. They need to take into account three additional factors: injection time, travel time, and flush time. By allowing time for the fertilizer to travel to the tail end of the field and using it as time-base-unit for injection and flushing, they would increase the level of uniform fertilizer distribution in their field. By using careful flush time that is based on travel time, they will also avoid deep leaching of mobile nutrients beyond the plant root zone. Such actions provide efficient use of nutrients, spare the environment, save precious resources, and minimize cost on inputs.

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EFFICIENCY OF JUTE FARMING AND PRESERVATION OF ENVIRONMENT IN INDIAN CONTEXT

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Abstract

Sustainable economic growth supplemented by the workable natural environment is one of the characteristics of an intergenerational distributional equity of wellbeing, and it would open more employment opportunities to the poor in a highly populous country and is one of the properties of intergenerational distributional equity of well-being during the period of an on going process of globalization in particular. The compliance of both the properties are discernible in growing jute and in manufacturing /using jute goods, too. We cannot deny that intensity of unemployment in an agrarian society is very much pronounced today. This luridness is perhaps one of the many causes, like disguised unemployment in agriculture. Jute agriculture is being focused on here. In our study, the empirical findings based on newly developed methodologies hardly exhibit the existence of surplus labor in jute cultivation. On the opposite side, manufacturing and using synthetic goods give rise to noncompliance of properties of sustainability. The degradation of environment and choice of labor displacing technology are closely associated with it. Revival of natural fibre jute, with appropriate invention/innovation through R&D and keeping in mind the economist-ecologist conflict, are under consideration even in the age of globalization where the market economy precludes the preservation of environment.

Key words: jute agriculture, surplus labor, economic growth, environmental preservation

Introduction

Natural fibre, jute, is gradually losing its market share since the 1960s with the emergence of its close substitutes nylon 66, polypropylene, and polyethylene in the process of invention as well as innovation despite the trend of rising environmental costs of producing/consuming these pollution-intensive synthetic goods. The conflict between the preservation of ecosystem services and or recuperation of a degraded environment in the less-developed countries like India, and the supply of bread to the common people at the expense of environmental services/capital, is appalling today. Total waste generation because of considerable size of production/consumption of synthetic goods, by-products of naphtha cracking and gasoline that resulted in an ever-burgeoning volume of social cost, causes inequality of wellbeing in the process of intergenerational time as well as an intra-generational time concept. The reason is that the market provides the incentives in favour of producing and consuming synthetic goods, which are cheap relative to the products of natural jute fibre. Economists do not necessarily believe that the market solves all problems, because the market does not always provide the best possible solution to society so far as environmental damage is concerned. The conflict between economists and ecologists is distinct as we incorporate the dimension of biodiversity into our comprehensive analysis. Synthetic goods do not degrade both biologically as well as chemically. As a result, social pollution arises, which should be considered as an environmental cost of producing / consuming synthetic goods.

If we are able to incorporate the social damage into this analysis, use of hydro-carbon-free jute products, perhaps, is to be seen more eco-friendly and healthy in the context of biodiversity. The export share from jute which is likely to be enhanced in future, so far as the property of sustainability of intergenerational distributional equity of well being is concerned. The market price per unit of synthetic goods in the short run is meager compared to jute goods because it excludes the environmental cost; however, its long-run cost, in view of sustainability, surpasses the prices of jute goods.

We may have a bird's-eye view of the degree of substitutability by inserting annual production of raw materials of synthetic goods in India. The production of raw materials of synthetic goods, high-density polyethylene (HDPE) and low-density polyethylene (LDPE), gives rise to an indistinct idea about substitution. The linear trend equations for the period 1990-1998 exhibits an increase in the production of HDPE by 50,000 and LDPE by 30,000 tones per year, respectively (source: CMIE) .

The present generation is enjoying the benefit of biodiversity. Loss of biodiversity has thus delayed to future generations for ruin to all. Soil degradation as a result of the use of polymers is very much relevant. These polymers make a layer in the upper surface of the soil and a natural tilling system does not work well. The agricultural land is adversely affected nutritionally, and hence, land becomes afflicted from the standpoint of fertility, which in turn affects the usual growth of biomass.

So if we are to withhold production of and use of ethylene, undertaking invention/innovation in respect of jute products may stimulate the jute market. On the contrary, jute pollutes in three stages: in the processing of jute fibre through retting, in the manufacturing of jute goods (generation of solid waste, discharged polluted water, and emission of smokes) with the old technology, and finally, from the consumption of jute goods. However, the pollutants generated are perhaps below nature's assimilative capacity **A** (may be quantifiable)**. A** taken as a resource varies from region to region. The revival of eco-friendly, labor-intensive jute goods in place of today's eco-inimical synthetic goods does not only support the property of environmental sustainability, but it also supplements employment, both in agriculture and industry, in compliance with the intergenerational sustainability property.

It is empirically found from the cost-structure of growing jute, that the cost of labor in cultivation of raw jute ranges from nearly 60 to 70 percent of total cost per acre; it is a labor-intensive crop. Costs of required inputs like irrigation, fertilizers, pesticides, and implements are very insignificant as far as cost-structure of our primary data are concerned. The higher relative cost of growing raw jute may be explained by the exaggerated imputed wage of family labor and greater intensity of family labor deployment during the phase of data collection. We collected data in two phases. We cannot deny that exaggeration of imputed wage of family labor during the survey was distinct. The correct data may be captured if a collection is undertaken in three phases despite lack of awareness of general farmers.

Subsidized employment does not sustain the market under liberalizations in particular, because of high cost, low efficiency, and further requirement of subsidy; yet it generates more welfare. It is not undeniable that employment is a cost from commercial point of view, but it is a benefit from the social point of view. Indeed, employment is the only dignified and sustainable means of satisfying the basic needs of the common people. This dual significance of employment should be borne in mind in any people-oriented social planning.

Two important points may be the benchmark in growing jute in India. It is a labor-intensive crop that demands relatively large amounts of manpower in rural areas, including retting in particular. The ongoing process of globalization invites labor displacing technology today and it is empirically established that the rate of unemployment under economic reform is high in rural sector as compared to urban areas. (Bhaumik, 2004) It has a complementary role in the growth of rural employment in an agrarian society. Again the labor cost percentage of market value of final output is comparable to other crops in such a way that it would not be preclusive to jute cultivation.

The burden of labor cost may be better appreciated if instead of taking relative labor cost, we consider labor cost as a percentage of value of output. In this respect, it is comparable. Secondly, it is out and out an eco-friendly crop, which does not harm biodiversity; its use/production has no negative externalities. The dilemma of rapid industrialization under globalization and preservation of green environment demands a workable human atmosphere.

We applied our own methodology to estimate empirically how significantly, if at all, labor can be saved in jute cultivation, the estimation of surplus labor. The methodologies developed on our own to estimate surplus labor are applied to primary data and the derived result does not convey much about the existence of surplus labor due to a bad fitting of regression equations.

Katwa is one of the subdivisions of the Burdwan district. The villages under survey are within the geographical territories of Nadia, Murshidabad, and Birbhum districts, as these are borderline districts of West Bengal. The economy of Katwa is exclusively based on agriculture and rural non-farm activities. The jute crop occupies a very small area under cultivation in the Burdwan district relative to Nadia, Murshidabad, north and south 24-paragons.

From the cost-structure of raw jute, we may conclude that the most important item of cost components is labor, covering 60-70% of total cost. At present stage, we are trying to investigate the reasons behind the higher cost of producing raw jute in Burdwan district, especially in the Katwa subdivisional area. The relatively high cost of cultivation of jute may be explained by either higher wage rate or greater amount of employment per acre. Although low productivity of agricultural labor may raise the cost of growing jute, which may be owing to the worse technical competence at the farm level, bad management, or depleted resources at the disposal of the farmers. In our present area of study, we hypothesize that there exists a considerable amount of surplus labor that may cause the cost of production of raw jute to rise relatively high. In the present context, we want to estimate quantitatively how significantly, if at all, surplus labor exists in jute cultivation.

We will try to keep attention to the methodology of measuring it, so that it can be free from weakness as far as possible. We will try to use such methods, as should not depart from the original concept of surplus labor, though it is difficult to estimate disguised unemployment from the production point of view, because it is not easy to find the actual case of withdrawal with other things remaining the same. Such a withdrawal may take place side by side with other factors of production changes. Thus, the direct method of measuring surplus labor is hardly applicable in respect to the data available. Let us now consider some indirect methods of ascertaining surplus labor.

One indirect method of measuring surplus labor is based on the postulation that production of raw jute per acre is proportional to the proportion of family labor to total employment. Total employment per acre is supposed to be increased as employment of family labor relative to total employment increases, because the work equilibrium reaching to marginal productivity is equal to zero, instead of marginal productivity being equal to wage rate. The higher the proportion of family labor to total employment the greater the output per acre, if the existing workers perform their full quota of work. Accordingly, because of the later work equilibrium, the farm with a higher proportion of family labor is assumed to correspond to greater output. If the output per acre is inversely related to the proportion of family labor to total employment, it signifies that laborer per acre increases; but labor per acre does not rise, that is, workers are not doing a full quota of work; indicating the existence of surplus labor. The existence of surplus labor may also be estimated by the magnitude of output elasticity with respect to employment. If the value of output elasticity with respect to employment is lowest, this indicates that production responsiveness to the change in employment pattern is much smaller, signifying the existence of surplus labor. We need farm-level primary data through some field work, and regression analysis may help us to get a quantitative relationship between the explained and the set of explanatory variables. Other statistical tools could also be applied for data analysis.

Another indirect method of estimating surplus labor is based on the relationship between employment per unit of output and proportion of family labor to total employment. The existence of surplus labor may be justified by the fact that both employment per unit of output and the proportion of family labor to total employment move in the same direction. It signifies that labor per unit of output increases as employment of family labor relative to total employment increases. It means that with the increase in employment of family labor, the work effort or work intensity per worker is declining. The resulting effect is that the growth rate of employment is greater than the growth rate of output. This approach of estimating surplus labor is to be applied by taking primary data.

We may approach the subject in another way: surplus labor is the excess of actual employment over the required employment. The estimated required employment is based on certain norms. No small farm will use hired labor unless its family labor is exhausted, and there is no surplus labor on a farm where only hired labor is employed. On a farm where only hired labor is used, the actual number of workers may be identified with the number of workers required, since it may be reasonably assumed that each hired laborer is doing a full load of work in a competitive labor market. Thus, we consider the farms where only hired labor is used as standard farms, where actual employment is treated as required employment.

Now, we classify the whole set of farms into two groups, one group consists of standard farms where the proportion of employment of family labor to total employment is zero, and the second group consists of non-standard farms where the proportion of family labor to total employment is positive. After formation of two distinct groups, we try to find the quantitative relationship between total required employment per acre and production of jute per acre of the standard farms, with the assumption that employment of required labor is proportional to production per acre. With the help of this estimated equation, if it is well fitted, we may find estimated required employment per acre corresponding to each and every production per acre of non-standard farms. If estimated, required employment falls short of actual employment, the estimated surplus labor is positive. The empirical work depends on primary data and we shall try to select farms in such a way that agro-climatic conditions remain the same for all farms.

To verify the above proposition we collected primary date covering 51 farms in the Nadia and Burdwan districts in September 2005. The farms belonged to the villages of Gangatikuri, Goalpara, and Bikaihat of the Burdwan district and also the villages of Matiari, and Sadhuganj of the Nadia district. The villages were selected on the basis of convenience. The farms belonging to different villages were selected on the basis of purposive sampling.

Here, the method of jute cultivation was found to be highly labor intensive. From land preparation to harvesting and final processing of jute, the farms hardly used any sort of mechanical devices. It was observed that the relatively large farms, which rarely appeared in our sample, are almost always based on hired labor. On the contrary, there is a tendency on the part of small farms to use a greater proportion of family labor to total employment. Still the organization of the farm structure is almost the same for all adjacent farms.

By assuming a linear and log-linear relationship, we regressed the production of raw jute per acre (Q) on total employment per acre (N), and the total employment per acre (N) on proportion of family labor to total employment (P) in respect of primary data. The estimated equations are given below:

Q = 8.98 + 0.01N
(1.24) (0.01)
(7.24) (1.20) R^2 = 2.87%, D-W = 1.34

N = 98.98 - 7.41P
(2.88) (7.29)
(30.95) (-1.01) R^2 = 2.06%, D-W = 1.04

Log Q = Log1.58 + 0.17LogN
(0.50) (0.11)
(3.07) (1.56) R^2 = 4.76%, D-W = 1.04

Log N = Log4.64 - 0.17LogP
(0.036) (0.006)
(122.95) (-0.36) R^2 = 0.26%, D-W = 1.01

So as R^2 and t- ratios are concerned, the quantitative relations are badly fitted. Variations of the values of the dependent variables are not explained by the variations of the values of independent variables. The above set of equations does not provide establishment of a water-tight argument favoring the existence of surplus labor in jute agriculture.
To follow the second way of measurement, we took the employment per unit of output (E), as explained and the variable and proportion of family labor to total employment (P), as explanatory variable. We regressed employment per unit of output (E) on the proportion of family labor to total employment. The data fitted to both linear and log linear equations as follows:

E = 8.48 + 0.01 P
(0.31) (0.80)
(26.77) (0.02) R^2 = 0.0009%, D-W = 1.06

Log E = Log2.12 + 0.0004 Log P
(0.4) (0.007)
(51.35 (0.05) R^2 = 0.0005%, D-W = 1.09

Both the values of R^2 and t-ratios in both functional forms hardly favor any significant relationship between employment per unit of output and proportion of family labor to total employment. The resulting empirical findings render that the existence of surplus labor in our area of study becomes very indistinct, explained by these bad-fitted relations.

This way of measuring surplus labor (Approach III) is based upon the existence of standard farms in the sample with which we compare non-standard farms. In our sample of 51, we have only 17 farms that employed only hired labor. We have the data on employment per acre (N) and production of raw jute per acre (Q) of 17 standard farms. Now, by assuming a linear relationship we regressed required employment on the production of jute of 17 farms, deploying zero family labor and trying to identify the best-fitted equations. The OLS method gets the best-fitted estimated equations.

$N = 15.39 + 6.87\,Q$
(26.11) (2.56)
(0.57) (2.67) $R^2 = 32.35\%$, D-W = 1.10

$N = 8.34\,Q$
(0.35)
(23.36) $R^2 = 30.84\%$, D-W = 1.18

$\text{Log}\,N = \text{Log}2.58 + 0.17\text{Log}Q$
(0.70) (0.30)
(3.63) (2.61) $R^2 = 31.32\%$, D-W = 1.05

$\text{Log}\,N = 1.90\text{Log}\,Q$
(0.02)
(76.46) $R^2 = 29.31\%$, D-W = 1.48

The log-linear equation with intercept is a relatively well-fitted equation so far as t-ratios and R^2 are concerned, though it is not supposed to be best fitted. Now, corresponding to each and every production (Q) of 34 non-standard farms, we obtain the corresponding expected required employment. By comparing actual and expected required employment, we identify the farms rendering expected surplus labor, as actual farm employment surpasses the expected required employment; the surplus labor at the farm level probably exists. Now we are in a position to classify the farms where the expected surplus labor is positive. Out of 34 non-standard farms, we have only 20 farms exhibiting positive surplus labor as per our approach III. But the expected surplus labor may not be equivalent to actual surplus labor. To verify the effectiveness of approach III, we apply again the first method. The estimated linear equations are as below:

$Q = 7.14 + 0.29\ N$
(2.16) (0.02) $R^2 = 8.62\%$ D-W = 1.74
(3.3) (1.3)

$Log\ Q = Log\ 0.83 + 0.32\ Log\ N$
(1.05) (0.23) $R^2 = 9.5\%$ D-W = 1.69
(0.79) (1.37)

$N = 98.93 - 7.18\ P$
(3.59) (8.14) $R^2 = 4.14\%$ D-W = 1.48
(27.55) (- 0.88)

$Log\ N = 4.53 - 0.02\ Log\ P$
(0.04) (0.03) $R^2 = 2.06\%$ D-W = 1.47
(94.5) (- 0.62)

If surplus labor actually exists on each of 20 farms, the proportion of family labor to total employment, the total employment moves in the same direction and production is responsive when there is a change in employment. To verify the effectiveness of our third method, it is being strongly established that values of R^2 for all quantitative relations improved as compared to first set of equations. However, the relative smaller values of R^2 and t- ratios corresponding to the final set of equations do not reflect reality. Accordingly, we cannot strongly establish that surplus labor exists actually even in the 20 farms where the expected surplus is positive. Perhaps the application of our third approach, where farms deploy positive surplus labor, to the first method, will help us in finding disguised unemployment. We cannot deny that our approaches are supplementing an estimation of disguised unemployment quantitatively. However, farms are relatively efficient from the standpoint of utilization of labor force, even in the situation where disguised unemployment might be present in rural agriculture.

Non-Parametric Approach

Measurement of performance of any organizational unit in terms of sophisticated and complex econometric tools is not only pertinent to finer econometric analysis but also has an abiding relevance to the efficiency of the farm concerned. Each farm is taken as a separate unit, working independently under an endemic cumulative impact of management, ambit of environment, resource availability, input combination etc. But all of them cannot attain the optimal output-point. Efficiency of management and organizational skills depends on collection of decision-making units (DMUs) of the farms undertaken in the sample. We again verify how well the farms work despite the outcome of non-existence of disguised unemployment in rural Bengal. Data envelop analysis (DEA), a non-parametric approach , does not require any functional form or specific assumption in stochastic terms and some other restrictions. DEA optimizes each individual farm's observations with the objective of computing a direct piece-wise determinant by the set of Pareto-efficient DMUs. It computes the best performance measures for each DMU relative to other DMUs under consideration. The only requirement is that each DMU lie on or below the efficient benchmark.

The technique of DEA is based on linear programming intended for measuring relative efficiency of a group of agricultural farms of multiple deployment of a combination of inputs that obviously corresponds to multiple outputs. In our study, based on primary data, we have inputs of labor employment per acre to produce jute and jute acreage for 51 farms. The output of each farm is assumed to be only jute. In our simple model, we have 51 DMUs to evaluate. The varying amounts of inputs ($m = 2$, labor and land) correspond to varying amounts of s different outputs ($s = 1$). The DMUs are denoted by $j = 1,2,3, \ldots\ldots\ldots\ldots.51$

$$X_j = (x_{ij})$$

$$Y_j = (y_{rj})$$

Table 1. Data envelop analysis (DEA).

Sl.no	Q	L	A	Q-tar (vrs)/Q	Q-tar	L-targ	A-tar	CRS-Eff	VRS-Eff	Scale-Eff	RTS
1	11.23	86	1.16	0.773	14.52	78	0.83	0.701	0.773	0.907	drs
2	10.89	92	1.65	0.750	14.52	78	0.83	0.635	0.75	0.847	drs
3	10.58	101	0.5	0.808	13.086	72.31	0.5	0.588	0.808	0.727	drs
4	11.09	96	0.99	0.764	14.52	78	0.83	0.622	0.764	0.814	drs
5	10.08	80	0.99	0.694	14.52	78	0.83	0.677	0.694	0.975	drs
6	9.07	83	0.66	0.658	13.781	75.07	0.66	0.599	0.658	0.91	drs
7	10.28	87	1.65	0.708	14.52	78	0.83	0.634	0.708	0.896	drs
8	12.1	83	0.99	0.833	14.52	78	0.83	0.783	0.833	0.94	drs
9	14.52	78	0.83	1.000	14.52	78	0.83	1	1	1	-
10	9.68	90	1.65	0.667	14.52	78	0.83	0.577	0.667	0.866	drs
11	9.07	66	7.27	0.737	12.3	66	3	0.736	0.737	0.998	irs
12	9.07	72	4.96	0.675	13.433	72	3	0.675	0.675	1	-
13	9.68	90	8.26	0.667	14.52	78	0.83	0.576	0.667	0.864	drs
14	10.58	75	6.61	0.756	14	75	3	0.756	0.756	1	-
15	8.06	60	0.99	0.863	9.336	60	2	0.721	0.863	0.835	irs
16	9.07	66	3.96	0.737	12.3	66	3	0.736	0.737	0.998	irs
17	9.07	66	2.64	0.746	12.164	66	2.64	0.736	0.746	0.987	irs
18	9.07	75	1.32	0.650	13.95	75	1.32	0.649	0.65	0.999	irs
19	10.07	90	0.99	0.694	14.52	78	0.83	0.601	0.694	0.867	drs
20	12.1	127	1.65	0.833	14.52	78	0.83	0.512	0.833	0.614	drs
21	10.08	101	0.99	0.694	14.52	78	0.83	0.539	0.694	0.777	drs
22	10.58	108	1.32	0.729	14.52	78	0.83	0.526	0.729	0.722	drs
23	9.07	83	2.64	0.625	14.52	78	0.83	0.586	0.625	0.938	drs
24	10.28	114	3.31	0.708	14.52	78	0.83	0.484	0.708	0.683	drs
25	11.75	109	2.98	0.809	14.52	78	0.83	0.578	0.809	0.714	drs
26	10.58	121	1.32	0.729	14.52	78	0.83	0.47	0.729	0.645	drs
27	12.1	87	1.65	0.833	14.52	78	0.83	0.747	0.833	0.896	drs
28	12.96	108	1.16	0.893	14.52	78	0.83	0.645	0.893	0.896	drs
29	10.8	96	2.31	0.744	14.52	78	0.83	0.604	0.744	0.896	drs
30	11.34	91	2.64	0.781	14.52	78	0.83	0.668	0.781	0.896	drs
31	11.34	93	1.32	0.781	14.52	78	0.83	0.655	0.781	0.896	drs
32	10.08	90	0.992	0.694	14.52	78	0.83	0.602	0.694	0.896	drs
33	8.07	90	0.992	0.556	14.52	78	0.83	0.482	0.556	0.896	drs
34	7.86	88	0.66	0.570	13.781	75.069	0.66	0.491	0.57	0.896	drs
35	8.47	106	2.64	0.583	14.52	78	0.83	0.429	0.583	0.896	drs
36	11.2	96	1.32	0.771	14.52	78	0.83	0.627	0.771	0.896	drs
37	9.68	83	0.66	0.702	13.781	75.069	0.66	0.639	0.702	0.896	drs
38	10.08	99	0.992	0.694	14.52	78	0.83	0.55	0.694	0.896	drs
39	9.83	96	0.66	0.713	13.781	75.069	0.66	0.566	0.713	0.896	drs
40	9.07	87	1.98	0.625	14.52	78	0.83	0.559	0.625	0.896	drs
41	8.94	92	2.15	0.616	14.52	78	0.83	0.521	0.616	0.896	drs
42	7.5	55	1	1.000	7.5	55	1	0.732	1	0.896	irs
43	13	77	1	0.907	14.332	77	1	0.907	0.907	0.896	-
44	12	92	0.5	0.917	13.086	72.31	0.5	0.729	0.917	0.896	drs
45	12.3	66	3	1.000	12.3	66	3	0.998	1	0.896	irs
46	12	68	0.25	1.000	12	68	0.25	1	1	0.896	-
47	11	68	1	0.901	12.21	68	1	0.869	0.901	0.896	irs
48	10	96	0.5	0.764	13.086	72.31	0.5	0.583	0.764	0.896	drs

Sl.no	Q	L	A	Q-tar (vrs)/Q	Q-tar	L-targ	A-tar	CRS-Eff	VRS-Eff	Scale-Eff	RTS
49	14	75	3	1.000	14	75	3	1	1	0.896	-
50	10	68	1	0.819	12.21	68	1	0.79	0.819	0.896	irs
51	12.5	83	2	0.861	14.52	78	0.83	0.808	0.861	0.896	drs

Q: production per acre
L: total employment per acre (family + hired)
A: jute acreage
Q -tar: targeted output
CRS-Eff: efficiency under constant returns to scale
VRS-Eff: efficiency under variable returns to scale
Scale Eff : scale efficiency
RTS: returns to scale

X_{ij} = amount of i th input required to by the j th farm (DMU) where I = 1,2
Y_{rj} = amount of r th output produced by the j th farm (DMU) where r = 1
X = m x n matrix of input (2X51)
Y = s x n matrix of outputs (1X51)

The various models for data envelope analysis are in search of n DMUs determining parts of envelopment surface. Here we could assume constant returns to scale (CRS), as well as variable returns to scale (VRS). Measurement of efficiency of the farms under the condition of VRS reflects more meaningful results for the real-life farming system because of the set of feasible output combinations. Findings of the DEA with the help of a computer-package program suggest that nearly 86 percent of the farms are relatively efficient on the basis of the additional assumption that the ratio of output targeted to actual output (Table 1 , column –5) equals 0.7 or above. Though it has no scientific justification ,it has been taken as a proxy value. The efficiency of the farms under CRS as well as VRS is also examined in Table 1. Besides this, the scale efficiency of most of the farms is close to one. The efficiency of the farms does not depend on the nature of employment of the labor force, despite the existence of no surplus labor in jute farming in rural Bengal. The epilogue elevates the efficiency of the jute farms, which is not positively correlated to the proportion of family labor to total labor employed in jute growing undertakings in the districts mentioned. We cannot deny that the huge surplus labor in Indian agriculture is a benchmark today.

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POLYACRYLAMIDE (PAM) FOR IRRIGATION RUNOFF MANAGEMENT

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Abstract
Nearly two million U.S. irrigated acres safely use PAM for erosion control, water quality protection, and infiltration management, preventing 20 million tons of soil loss annually. Nutrients, pesticides, chemical oxygen demand, weed seeds, and pathogens in runoff from PAM-treated irrigation are greatly reduced. Typical annual PAM application amounts are < 10 kg ha^{-1}. At these rates, infiltration is improved on medium to fine-textured soils. PAM applied at recommended rates has little or no effect on soil microflora and microfauna. Field research has shown that applications of up to 5.4 ton ha^{-1} active ingredient (a.i.) of PAM have only modest effects on soil microflora numbers and function and that PAM degrades at a rate of at least 9.8% y^{-1}. Key points of PAM technology are presented.
Key words: water quality, erosion, infiltration, environmental safety, acrylamide

Introduction

This paper summarizes anionic polyacrylamide (PAM) use for erosion and infiltration management in irrigated agriculture with emphasis on environmental benefits and safety. The full scope of PAM technology was thoroughly reviewed by Sojka et al. (2007). Comprehensive information on PAM use for erosion control also can be found at <http://sand.NWISRL.ars.usda.gov/pampage.shtml>. Lentz et al. (1992) reported the first field research of a practical approach to halting furrow irrigation-induced erosion with PAM. PAM applied in irrigation water at 1-2 kg ha^{-1} per irrigation halted 94% of erosion (Lentz and Sojka, 1994). Soil in the irrigation furrow is only treated as water crosses the field (the advance), and PAM application is halted when runoff begins.

To ensure environmental safety, a food-grade class of anionic PAM is used. Charge density is typically 18 percent, but can range from a few percent to more than 50 percent. These PAM molecules have more than 150,000 chain segments per molecule and a molecular weight of 12 to 15 Mg $mole^{-1}$; they are manufactured to high purity and are used in many sensitive applications. They have residual acrylamide monomer (AMD) contents of <0.05%, ensuring safety for humans or aquatic species. Common uses of anionic PAMs were listed by

Wallace et al. (1986) and Barvenik (1994) and include sewage sludge dewatering; mineral separation processes; paper manufacture; clarification of refined sugar, fruit juices, and drinking water; thickening agents in animal feeds; antiscaling in steam processes in contact with food; and as a coating on paper used for food packaging.

Flowing irrigation water without PAM detaches and disrupts aggregates, transporting the solids in the flow, leading to erosion and water quality impairment of the runoff and to surface sealing along the flow path that reduces infiltration. Sealing is intensified by water droplets from sprinklers or rain. Droplets have additional kinetic energy, adding to aggregate disruption and dispersion. Bridging cations in the solvating water link the anionic polymer to the predominately anionic mineral and organic particulate surfaces. Dissolved calcium in the solvating water improves PAM efficacy compared to low-electrolyte (pure) water. Because PAM stabilizes surface structure, in most medium-to fine-textured soils, infiltration is increased compared to nontreated water (Lentz et al., 1992; Lentz and Sojka, 1994; Sojka et al., 1998a,b). As technology improves, PAM use with sprinklers may improve uniformity and rate of infiltration (Aase et al., 1998; Bjorneberg et al., 2000; Bjorneberg and Aase, 2000). With PAM in the water, soil structure is stabilized and surface sealing is reduced; water droplets enter the soil where they land, rather than causing surface seals that induce runoff and redistribution of water.

Environmental Considerations

PAM use with irrigation for erosion control benefits water quality in many ways. By preventing erosion, it reduces desorption opportunity of sorbed nutrients and pesticides, and limits dissolution of soil organic matter that would otherwise elevate dissolved organic carbon (DOC) in runoff and raise biological oxygen demand (BOD) (Agassi et al., 1995; Bjorneberg et al., 2000; Lentz et al. 1998, 2001).

Because PAM raises the viscosity of water flowing through soil pores (Malik and Letey, 1992), PAM effects on infiltration are a balance of seal prevention (increased infiltration) and increased viscosity (reduced infiltration). Lentz (2003) used the viscosity effects plus other application and management strategies for furrow, pond, and canal sealing, and improved infiltration uniformity along long irrigation furrows.

PAM is not regulated under FIFRA (Federal Insecticide, Fungicide and Rodenticide Act, 1996), but it is regarded as a macropollutant with low toxicity and side effects. PAM has been used widely for decades in food, environmental and other sensitive applications, involving significant disposal or release to the environment. Caution is warranted, but the low toxicity of PAMs, especially ***anionic*** PAMs, means that if used to prescribed guidelines, human or environmental health risk is small. Barvenik (1994) and Deskin (1996) summarized PAM safety considerations, noting that PAMs generally exhibit low toxicity to mammals, with high acute LD_{50} by oral and dermal routes (>5g kg^{-1}). There were no significant adverse effects in chronic oral toxicity studies, no compound-related reproductive lesions in a three-generation rat study, and only slight dermal and ocular irritation at high doses (Stephens, 1991). Human epidemiologic studies showed no association between occupational PAM exposure and tumors, paralleling the chronic animal studies. The large size of these PAM molecules precluded movement across membranes, preventing gastrointestinal absorption (Stephens, 1991).

Rigorous tests of PAM concentration downstream from application sites showed that, properly applied, no serious risk of PAM loss is posed (Lentz et al., 2002; Ferguson, 1997). If a minor PAM loss occurs, its strong surface-attractive properties result in its rapid removal via adsorption on and flocculation of suspended solids in the runoff within a few hundred meters of transport from an application site (Lentz et al., 2002)-actually providing water quality improvement in tail ditches when small PAM losses occur.

Malik et al. (1991) reported that PAM applied via infiltrating water is irreversibly adsorbed in the top few millimeters of soil once dry. Lu and Wu (2003) reported that PAM penetrated into organic matter-free soil at 20 to 30 mm. PAM delivery via furrow streams is very efficient, because it only needs to stabilize the thin veneer of soil directly active in the erosion process. In furrow irrigation, PAM treats about 25% of the field surface area to shallow depth, requiring only 1-2 kg ha^{-1} of PAM per irrigation.

PAMs used for erosion and infiltration managment contain <0.05% AMD. AMD is a neurotoxin, but at this AMD content, anionic PAMs are safe, used as directed at low concentrations (see discussion below). In greenhouse soil, PAM degraded at 10% per year due to physical, chemical, biological, and photochemical processes (Azzam et al., 1983).

Because PAM is susceptible to UV degradation, its breakdown rate at the soil surface may be faster than 10% per year. Indirect evidence of faster breakdown of surface-applied PAM is the gradual loss of treatment effectiveness between irrigations (Lentz et al., 1992). Recent field research using carbon isotope natural abundance ratios showed a PAM degradation rate of at least 9.8% per year (Entry and Sojka, unpublished data, 2006). This rate is conservative, since carbon from degrading PAM molecules may be incorporated into soil organic matter, affecting the soil's apparent isotope signature. While non-ionic and cationic PAM formulations pose risk to aquatic organisms at low concentration (Biesinger and Stokes, 1986; Hamilton et al., 1994), anionic formulations do not. Anionic PAMs specified by NRCS for erosion and infiltration management (NRCS 2001, 2005) show no LC_{50} at concentrations up to 100 ppm. Furthermore, PAM toxicity determined in deionized water has lower LC_{50} values than in natural waters, because of the action of suspended sediments and dissolved organic compounds present in natural waters (Buchholz, 1992; Goodrich et al., 1991; Hall and Mirenda, 1991). Dissolved humic substances raise LC_{50} measurements an order of magnitude for 5 ppm suspended matter (Goodrich et al., 1991) and two orders of magnitude for 60 ppm (Hall and Mirenda, 1991). Carey (1987) and Biesinger et al. (1976) showed that organic carbon and bentonite clay also reduced PAM toxicity to test species. Absence of a measurable LC_{50} for anionic PAM concentrations up to 100 ppm gives a ten-fold safety margin for the 10 ppm PAM concentration applied to agricultural fields using the NRCS application standard. Two to three orders of magnitude of added safety exists even if runoff flows directly into a riparian body (Lentz et al., 2002). Sojka et al. (2007) reviewed a list of aquatic species toxicity, confirming safety of erosion-control concentration levels.

PAM used for erosion control reduces nutrients in runoff carried on or released from sediment. Lentz et al. (1996) applied 0.25 to 0.50 ppm PAM to furrow inflows during a 24 h irrigation; runoff was sampled at 4 and 9 hours for P. PAM had little effect on ortho P but a 25% reduction in total P. Lentz et al. (1998) compared treating furrow advance flow (only) with 10 ppm PAM or treating with 1 ppm PAM throughout the irrigation. Water quality improved compared to controls in both cases. Dissolved reactive P and total P concentrations in control tailwater were five to seven times, and chemical oxygen demand (COD) of controls were four times those measured in PAM treatments. Several reports show that PAM use reduces runoff nutrients (Lentz et al., 2001; Entry and Sojka, 2003; Sojka et al., 2005; Bjorneberg et al., 2000).

Agassi et al. (1995) studied runoff loss of the herbicide napropamide from Hanford sandy loam soil. Treating with 10 ppm anionic PAM greatly reduced loss of sediment and napropamide. Singh et al. (1996) studied PAM treatment of furrow irrigation on loss of the miticide kelthane from a Capay clay soil. PAM applied at 10ppm greatly reduced sediment and miticide loss and increased infiltration. In Idaho, 10 ppm PAM-treated (only during advance) furrow irrigation runoff was compared to controls for N, total, and ortho P; and the pesticides terbufos, cycloate, EPTC, bromoxinil, chlorpyrifos, trifluralin oxyfluorfen, and pendimethalin in sugarbeet and onion fields (Bahr and Steiber, 1996; Bahr et al., 1996). PAM reduced sediment loss up to 99% and N and P concentrations up to 86% and 79%, respectively, and greatly reduced pesticide losses.

Australian studies compared conservation tillage and PAM to control erosion and prevent endosulfan loss in runoff (Waters et al., 1999a; Hugo et al., 2000). In surface irrigation, either PAM or conservation tillage controlled soil and endosulfan loss by 70%. Oliver and Kookana (2006a,b) reported that PAM reduced loss of endosulfan, bupirimate, and chlorothalonil by 54, 38, and 49%, respectively.

Endemic and manure-applied microorganisms carried by furrow runoff were reduced by PAM in irrigation water (Sojka and Entry, 2000; Entry and Sojka, 2000; Entry et al., 2003). Common removal rates ranged from 50 to 90%. Similarly, PAM reduced runoff loss of weed seeds 62 to 90% for six major weeds (Sojka et al., 2003). Weed seed and microorganism sequestration pointed to management that should reduce pesticide use.

Effects of PAM on bacterial biomass in soils and waters were varied (Mourato and Gehr, 1983; Nadler and Steinberger, 1993; Steinberger et al., 1993; Kay-Shoemake et al.,1998a,b). Larger populations of heterotrophic bacteria were found by Kay-Shoemake et al. (1998a) in PAM-treated soils planted to potatoes, but not if planted to beans. These and other studies showing increased or decreased bacterial numbers for PAM-treated soil suggest that PAM effects are site-, season-, and cultural practice-specific and interact with nutrient levels, crop type, or herbicide regimes. Bacterial enrichment cultures, derived from PAM-treated soils, were capable of growth with PAM as a sole N-source but not a sole C-source, whereas AMD served as either a sole N- or C-source for bacterial growth (Kay-Shoemake et al., 1998b). Grula et al. (1994) showed that PAMs are an N source for bacteria and stimulate growth of a number of Pseudomonas sp.; only cationic PAMs were toxic to cultured organisms for PAM concentrations under 0.2%.

Sojka et al. (2006) reported the effects of ultra-high PAM application rates to irrigated soils. Over a six-year period, 1000 kg ha^{-1} y^{-1} of anionic PAM were added to soil. At the study's end, analyses were done on plots receiving 2691 or 5382 kg a.i. PAM ha^{-1}. Active bacterial, fungal, and microbial biomass were not consistently affected by high PAM additions. Even with these massive PAM applications, effects on microorganisms were moderate and were driven more by sampling date than by PAM treatment. In June and August, active bacterial biomass in soil was 20-30% greater in the controls than where soil was treated with 2691 or 5382 kg PAM ha^{-1}, but there were no significant differences in July. There were no differences in active bacterial biomass between the 2691 or 5382 kg PAM ha^{-1} treatments, regardless of sampling time. Control-treatment active-fungal biomass was 30–50% greater than soil treated with 2691 or 5382 kg PAM ha^{-1} in June and July, but not in August. There was no difference in soil-active-fungal biomass between the 2691 or 5382 kg PAM ha^{-1} on any sampling date. Soil-active microbial biomass was 27-48% higher in control than in soil treated with 2691 or 5382 kg PAM ha^{-1}, except in June, for the 5382 kg PAM ha^{-1} treatment. Nutritional characteristic analysis (Biolog GN) showed separation of the nonamended control soils from high PAM treatments for the June sampling, but not for July or August. Whole-soil, fatty-acid profiles (FAME) showed no soil microbial community change for any PAM application rate or date. In contrast, fatty-acid and Biolog analyses both indicated that the microbial communities present in all plots at the June sampling differed from those sampled in July and August, both taxonomically and metabolically independent of PAM treatment. Thus, despite large PAM additions over six years, there was little consistent effect on soil microbial biomass or metabolic potential (BIOLOG or FAME). Although measurable, effects on soil microbial population were inconsistent and moderate, considering the massive PAM amounts added. This suggests that concerns about PAM effects on soil microorganisms are not warranted, especially when weighed against the substantial erosion prevention and water quality protection resulting from more typical 5 to 10 kg ha^{-1} y^{-1} application rates.

Wallace et al. (1986) also reported on the effects of ultra-high rates of PAM application to soil. They compared the effect of adding 1 and 5% by weight of anionic PAM to soils with controls. The 1% PAM rate increased vegetative growth of wheat and tomato. The 5% rate produced growth results equivalent to controls.

Acrylamide Monomer (AMD)

Concern over PAM use is generally less for PAM itself than for residual AMD, a production contaminant. AMD is a neurotoxin and a suspected carcinogen in humans and animals (Garland and Patterson, 1967; WHO, 1985). High-dose AMD exposures have resulted in isolated human fatalities, temporary injury, or impairment with ingestion or extensive exposure to concentrations > 400 ppm AMD (Garland and Patterson, 1967). Exposure levels required to cause neurotoxic or carcinogenic effects in humans are several orders of magnitude above conceivable exposure resulting from environmental applications (10 ppm PAM, <0.05% AMD). The National Institute of Occupational Safety and Health (NIOSH) recommends an exposure limit of 0.03 mg m^{-3}, equivalent to 0.004 mg/kg/day for an 8-hour work day (NIOSH, 1992). For a 100 kg human, that equals 0.4 mg AMD, or 80% of the AMD per kg of the PAMs used for erosion control.

PAM does not degrade to AMD in soil due to the high-temperature requirement for that reaction (Mac Williams, 1978; Johnson, 1985; Wallace et al., 1986). Release of AMD by photodegradation of PAM is highly unlikely because the UV wavelengths at the earth's surface do not favor the reaction (Caulfield et al., 2003a,b; Crosby, 1976; Decker, 1989; Diffey, 1991; Suzuki et al., 1978, 1979) . Also, AMD is easily metabolized by microorganisms in soil and biologically active waters, with a half-life in tens of hours (Lande et al., 1979; Shanker et al., 1990). Bologna et al. (1999) showed that AMD is not absorbed by plants and breaks down rapidly when exposed to living plant tissue.

Many reports have drawn attention to health concerns related to AMD (Tareke et al., 2002; Ahn et al., 2002; Andrzejewski et al., 2004; Bacalski et al., 2003; Konings et al., 2003; Palevitz, 2002; Roach et al., 2003; Rosen and Hellenas, 2002; Svensson et al., 2003; Zyzak et al., 2003). Their papers and others report AMD content of cooked, baked, and fried foods. The range of AMD found in food tested by Svensson et al. (2003) was 25-2300 µg kg^{-1} AMD. Mean values for some popular foods were potato chips (1360 µg kg^{-1}), french fries

(540 μg kg^{-1}), bread crisps (300 μg kg^{-1}), cookies (300 μg kg^{-1}), tortilla chips (150 μg kg^{-1}), popcorn (500 μg kg^{-1}), and breakfast cereals (220 μg kg^{-1}). Various meat products ranged 30 to 64 μg kg^{-1}. The Food and Agricultural Organization and World Health Organization concluded that food contributes significantly to total AMD exposure, with average intake of 0.3 to 0.8 μg of AMD per kg of body weight per day. AMD concentrations in these common foods are 5 to 460 times greater than maximum residual AMD concentrations expected in irrigation water treated with 10 ppm of PAM products containing < 0.05% AMD. Yet, no neurotoxic effects are expected from AMD ingested in diets that include these foods. Human exposure to AMD from environmental uses of PAM containing <0.05% AMD applied at recommended rates is a substantially smaller AMD exposure risk than from common foods.

Conclusions

Anionic polyacrylamide (PAM) has proven to be a safe and economical soil and water additive for halting irrigation-induced erosion and managing infiltration. By far, its most significant environmental effects are preservation of soil sustainability through erosion prevention and improvement of return-flow water quality. In addition, there are numerous ancillary on-farm management benefits. PAM use for erosion control is one of the most user-friendly and farmer-accepted management practices to emerge in recent years to help farmers optimize production while protecting the environment.

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THE ROLE OF SUBSURFACE DRIP IRRIGATION FOR THE SUSTAINABILITY OF ARID-REGION AGRICULTURE

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Abstract
The adoption of subsurface drip irrigation (SDI) provides a potential solution to the problem of low-water-use efficiency in production agriculture. Other advantages of SDI include reduced NO_3 leaching compared to surface irrigation, higher yields, a dry-soil surface for improved weed control, better crop health, and harvest flexibility for many specialty crops. Use of SDI also allows the virtual elimination of crop water stress, the ability to apply water and nutrients to the most active part of the root zone, protection of drip lines from damage due to cultivation and tillage, and the ability to irrigate with wastewater while preventing human contact. Yet, SDI is used only on a minority of cropland in the arid western U.S.A. Reasons for the limited adoption of SDI include high initial capital investment required, need for intensive management, and urbanization that is rapidly consuming farmland in parts of the western USA. The contributions of SDI to increasing yield, quality, and water-use efficiency have been demonstrated. The two major barriers to SDI sustainability in arid regions are economics (i.e. paying for the SDI system), including the high cost of installation; and salt accumulation, which requires periodic leaching, specialized tillage methods, or transplanting of seedlings rather than direct seeding.

Key words: irrigation, sub-surface drip irrigation

Introduction

Water-use efficiency in agriculture is often low, with plant use accounting for as little as 40-60% of water applied, and the remainder loss due to evaporation, surface runoff, or percolation into the vadose zone or groundwater (Smith, 1995). Low-water-use efficiency in irrigated agriculture results in wasted water resources and potential non-point source pollution of surface and groundwater resources with nitrates, salts, and agrichemicals including pesticides (Oster and Wichelns, 2003).

Agriculture accounts for 80% of water-use in the western states of Arizona, California, Nevada, New Mexico, and Utah (Koniecski, 2004). However, rapid urbanization in these areas threatens water supplies for agriculture. Increasing populations and decreasing supplies of good quality water are causing increased interest in use of water of marginal quality, including sewage effluent, for irrigation (Hills and Brenes, 2001).

Use of subsurface drip irrigation (SDI) provides one potential solution to these problems of low-water-use efficiency and decreasing irrigation water quality. Subsurface drip irrigation offers many advantages for crop production. These include increased water-use efficiency, reduction of nitrate leaching compared to surface irrigation, higher yields, maintenance of a dry soil surface for improved weed control and crop health, the ability to apply water and nutrients to the most active portion of the root zone, protection of drip lines from damage due to cultivation and other operations, and the ability to safely irrigate with wastewater while preventing human contact (Bar-Yosef, 1999; Camp, 1998; Lamm, 2002; Enriquez et al., 2003; Phene, 1995). Recent research has shown that with proper management, crop yields can be optimized with SDI while minimizing pollution through leaching losses of N (Thompson et al., 2000, 2002). Irrigation with SDI allows maintenance of low root-zone salinity, even when using irrigation waters containing appreciable salts (Oron et al., 1999; Oron et al., 2002).

Two potential shortcomings of SDI are its high initial cost and the potential for the development of soil salinity. Installation of SDI systems may cost >\$1000 ac^{-1} (Hanson and May, 2003). Conversion from conventional irrigation systems requires high capital inputs and increases in time required for irrigation design implementation and management. Costs of conversion to SDI often prevent producers from seeing the benefits of its adoption.

However, when amortized over the 10+ year life of the system, actual cost of SDI installation is only \$100 acre^{-1} year^{-1}. Proper management of SDI systems also requires higher time commitment and specialized training, which usually impact the economics of conversion to SDI.

Soil salinity is a common problem with SDI. Precise application of water and nutrients below the soil surface is a benefit of SDI, but leads to accumulation of salt near the soil surface. Net upward flow of water from the SDI emitter to the surface and loss of water to evaporation and transpiration can lead to high ECe values at the soil surface (Dasberg and Or, 1999). Management of accumulated salts leads to increased demand on time and money to maintain high levels of productivity. Reduction of salts accumulated at or near the soil surface is often accomplished using sprinklers, which leads to increases in labor and capital inputs (Hillel, 2000).

Despite its many advantages for crop production, particularly in arid regions, challenges remain that hinder more complete adoption of SDI. Two challenges, in particular, stand out: paying for the system, and long-term prevention of salt buildup in the soil. Our objective in this paper is to illustrate how our recent research in Arizona has contributed to our understanding of these issues.

Previous Studies

Field experiments with SDI were conducted during 1991-1999 to evaluate various outcomes of production of high-value crops with SDI. The results are described in several published papers (Pier and Doerge, 1995; Thompson and Doerge, 1996; Thompson et al., 2000, 2002). Briefly, each experiment consisted of factorial combinations of soil-water tension (dry to wet) and nitrogen-fertilizer rate (suboptimal to excessive). These two factors were chosen because they are the factors most likely to limit crop growth in arid regions. Crop yield and quality were measured at harvest, N fertilizer fate was estimated using the difference method, and net economic return was calculated using standard crop budgets. The objective of these experiments was to evaluate simultaneously the agronomic, economic, and environmental outcomes of crop production with SDI.

Spatial analysis techniques were used to evaluate outcomes of SDI production. Briefly, response surfaces for marketable yield, net economic return, and unaccounted N were developed using the SAS RSREG (SAS Institute, 1999) procedure. "Optimum" ranges on the response surfaces were defined as >95% of marketable yield and net economic return and unaccounted N of <40 kg ha^{-1}. This was estimated to represent the amount of N that could be lost and yet result in drainage water NO_3-N of <10 mg L^{-1}. Finally, we determined the ranges of N and soil-water tension where the three optimum ranges overlapped, that is, where agronomic, economic, and environmental production criteria were simultaneously maximized. Sample response surfaces are shown in Figure 1.

During 1991-1999, we evaluated agronomic, economic, and environmental outcomes of SDI production for four crops (watermelon, lettuce, broccoli, cauliflower) during eight cropping seasons (Pier and Doerge, 1995; Thompson and Doerge, 1996; Thompson et al., 2000, 2002). During six of the eight seasons, we identified regions where all three production criteria were simultaneously optimized. As shown in Figure 1, we also found that excessive N or water applications resulted in high amounts of N loss, and this N was probably lost from the soil profile. Therefore, good water and fertilizer management is still necessary when using SDI. We concluded from these experiments that production of high-yielding vegetable crops is compatible with environmental protection. These experiments did not, however, address some important questions about SDI in arid regions. First, the economic analysis did not include the cost of the SDI system. Second, each experiment utilized a new SDI installation; thus the effects of continued SDI production on soil-salt accumulation were not evaluated. A new project was initiated during 2002 (described below, "Long-Term Evaluation of SDI") to address these and other issues important to long-term use of SDI.

Economics of Subsurface Drip Irrigation

The economics of SDI installation and use by growers depend on several factors including 1) cost of system components and installation, 2) system longevity, 3) reduced input or management costs with SDI, 4) water cost, and 5) yield and quality increases with SDI compared to surface irrigation. Doubts about the ability pay for the cost of an SDI system with yield increases or savings in production costs are probably most responsible for inhibiting the adoption of SDI. In Arizona and other states of the U.S. Southwest, rapid urbanization, which is resulting in urban development of farmland also is limiting adoption of SDI.

Potential effects of several variables on outcomes of SDI production are illustrated in Figure 2. We assume 33% water savings with SDI compared to surface irrigation. This assumption is likely most valid when SDI is compared to surface-flood irrigation, and less valid when SDI is compared with sprinkler irrigation. The second key assumption is that use of SDI allows growers to save on costs of fertilizer and chemical applications. Application cost savings of \$25 ac^{-1} were used in this analysis. Different system installation costs were used in Figures 2A and 2B.

The curves in Figure 2 illustrate the influences of revenue, water cost, and SDI drip tape lifetime on the economic outcomes of SDI compared to surface-flood irrigation. In situations with a crop yielding low revenue, with a low water price, or with a short SDI system life, large revenue increases will be needed to pay SDI system costs. Revenue increases may come from yield or price increases. For example, an increase in cotton yield or quality (i.e. micronaire) induced by SDI could result in such revenue increases. For crops such as broccoli, yield increases may not translate into revenue increases because harvest costs are a major component of production costs.

Currently (2006), irrigation water in most irrigation districts in central Arizona costs \$35 to \$45 ac-ft^{-1}. It is evident from Figure 2 that, even with crops yielding high revenues, revenue increases must be achieved in order to pay for SDI systems. Higher water prices (e.g. \$80 ac-ft^{-1} as shown in Figure 2) would make the economics of SDI more favorable relative to surface-flood irrigation. Similarly, as length of system life increases, lower revenue increases are needed to pay for SDI systems.

Long-Term Evaluation of SDI

In 2002, a demonstration/research project ("AZdrip", Web site: http://ag.arizona.edu/azdrip) was established at the University of Arizona's Maricopa Agricultural Center. Objectives of the project were to 1) evaluate management practices for efficient and sustainable irrigation using SDI, and 2) provide information on and demonstration of SDI management practices for Arizona growers.

The AZdrip project site features five large plots (67' x 405') with SDI or surface-flood irrigation. Large plots allow use of large-scale field equipment for effective demonstration of SDI management techniques. This project features long-term demonstration and evaluation of various aspects of crop production with SDI, in comparison with conventional surface-flood irrigation. Four of the plots have SDI installed in one of two configurations (Table 1, Fig, 3), with two different irrigation scheduling treatments (Table 1). With “high-frequency" SDI irrigation, soil moisture is kept near “field capacity” at all times. Five Irrometer® transducer-equipped tensiometers located in each high-frequency plot are interfaced with a Campbell Scientific® Datalogger to trigger irrigation (0.07") when the average soil-water tension reaches 10 cbar. Non-automated tensiometers in low-frequency plots are used to schedule irrigation events (0.5 - 1.0") when soil-water tension reaches 30-50 cbar. Surface irrigation is scheduled using the AZSched program. These combinations of SDI configuration and management were chosen based upon input from experienced SDI growers in Arizona.

The drip tubing is Netafim® Typhoon, 13-mil-wall thickness, 12-inch emitter spacing, and 0.18 - 0.25 gal/emitter/hr flow rate. A pump delivers 70 gpm @ 40 psi. Filters are two Netafim® 24" sand filters and one Netafim® disk filter. Acid, fluid fertilizers, and labeled insecticides are injected with two LMI Milton Roy® Electromagnetic Dosing Pumps. Irrigation water for the SDI plots is continuously acidified to pH 6.0. The entire system is flushed and chlorinated twice per season. Filters backflush automatically when pressure differential is >5 psi.

This project was established during summer 2002 and is intended to function for at least 10 years. The first crop, broccoli, was planted in October 2002 and harvested in February 2003. Seedless watermelon was planted in March 2003 and harvested in June-July 2003. A second broccoli crop was planted in November 2003 and harvested in March 2004. Another broccoli crop was planted in September 2004 and harvested in January 2005. A crop of watermelon was planted in April 2005 and harvested in July 2005. Barley was planted in November 2005 and harvested in April 2006. Seedless watermelon was planted in April 2006 and harvested in July 2006. We will continue to grow one to two crops per year. Short-and long-term evaluations allow comparisons of surface vs. SDI and among the various SDI treatments with respect to crop yield and quality, water-use efficiency, fertilizer and pesticide use, and economic returns.

Results of Demonstration Project

High-frequency irrigation with SDI benefited summer-grown watermelon crops, but did not benefit winter-grown broccoli crops compared to low-frequency irrigation with SDI (data not shown). Providing for high-frequency SDI irrigation for summer-grown crops (irrigation at least once/day) to maintain soil-water tension near 10 cbar should result in higher yield of watermelons. The plot design is conducive to high surface irrigation efficiency. However, the combination of generally lower water-use and higher yields with SDI have resulted in substantially higher water-use efficiency (crop produced per unit of water) with SDI than with surface irrigation (Fig. 4). With high-frequency SDI, cumulative water-use efficiency was twice that with surface irrigation. Thus, twice as much crop was produced using the same amount of water with high-frequency SDI than with surface irrigation.

We used actual commercial harvest yields determined in the demonstration plots, standard crop budgets (http://ag.arizona.edu/crops/vegetables/econ/vegecon.html), and actual SDI system installation costs to determine economic outcomes in the 'AZdrip' project. Although all systems—including surface-flood irrigation—were profitable, net returns over ownership and variable costs were three to six times higher with SDI than with flood irrigation during the first five seasons (Table 2). This advantage was most pronounced with watermelon crops.

Results of this project to date have demonstrated that use of SDI in Arizona crop production can consistently result in higher water-use efficiencies and higher economic returns than surface-flood irrigation.

Salt Accumulation with SDI

Continued use of SDI in arid regions will inevitably lead to salt accumulations detrimental to crop growth, unless salt accumulation can be minimized. Salt accumulation may pose the single largest constraint to sustainable use of SDI in Arizona. Detrimental salt accumulations can be avoided by a) cultural techniques with some crops (e.g. pre-irrigation followed by removal of the bed cap with cotton), b) periodic leaching with sprinklers, or c) transplanting of high-value crops.

In another experiment, we evaluated the effects of germination method (irrigation with SDI or sprinklers), depth of SDI tubing (7” and 10”), and irrigation water salinity (1.5 and 2.6 dS m^{-1}) on salt and Br distribution after one growing season. Following only one season, salt accumulation was high enough to significantly reduce the germination and establishment of the next crop. Although sprinklers were needed to achieve 100% establishment of the succeeding crop, timely rainfall can sufficiently decrease salinity and allow germination of a moderately salt-sensitive crop such as cantaloupe. Areas with exceptional high water quality (<0.5 dS m^{-1}) may not require sprinkler pre-irrigation for several years, as shown by Burt et al. (2003).

Methods for managing salt without use of sprinklers include transplanting and bed shaping. Using transplants may eliminate the need for sprinklers during establishment, because the root ball is placed from 5 to 10 cm below the zone of highest salt accumulation. However, sprinklers are often used with transplants to prevent desiccation, because several hours may be required for water to move from the drip tape to the root zone. Transplants may eliminate the need for sprinklers to manage salts, but require high capital inputs and may not improve the economic sustainability of SDI. Bed shaping has been introduced as a means to manage salt accumulation above the drip tape. This method involves forming the beds to a peak and pre-irrigating to move salts toward the peak. Tops of the bed are then removed into the furrow, leaving behind soil of low ECe. Direct seeding of some large-seeded crops can then occur without inhibition of emergence. Small-seeded crops that require precision planters cannot usually be direct-seeded into moist beds. Bed-shaping procedures may prove effective in some crop rotations by eliminating the need for sprinklers, but the excess water needed to pre-irrigate beds may be less economically feasible, depending on water cost.

Conclusions

To be sustainable, SDI must 1) achieve substantially higher water-use efficiency than surface-irrigation methods, 2) increase crop yield and quality, 3) be economically viable, 4) contribute in a positive way toward environmental protection, and 5) not lead to development of adverse soil properties (salinity, sodicity). Many authors have shown that SDI is superior to most other irrigation methods with respect to points 1, 2, and 4. However, the economic viability of SDI depends on several factors under the control of the grower, including SDI system life, crop produced, water savings, and application cost savings. However, there are other factors, not under the grower's control, including water cost and crop prices, that profoundly affect the economics of SDI. In arid regions, there is usually insufficient rainfall to leach salts from the zone of soil above the SDI tape. In this zone, detrimental salinity may result. In most cases, use of SDI in arid regions requires periodic use of sprinklers to leach salts.

Contributions of SDI to increasing yield, quality, and water-use efficiency have been demonstrated. Two major barriers to SDI sustainability in arid regions are economics, including the high cost of installation and low cost of water; and salt accumulation, which demands periodic leaching, specialized tillage methods, or transplanting.

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Table 1. Plot treatments for the AZdrip project.

Plot	SDI Tubing Placement	Irrigation Treatment
1	3 SDI lines per 80" bed 10 beds per plot	Automated high frequency
2	1 SDI line per 40" bed 20 beds per plot	Automated high frequency
3	3 SDI lines per 80" bed 10 beds per plot	Low frequency
4	None	Surface flood irrigation
5	1 SDI line per 40" bed 20 beds per plot	Low frequency

Table 2. Return over ownership and variable costs ($ ac^{-1}) in the 'AZdrip' SDI demonstration project. Values assume amortizing cost of SDI tubing over 10 years.

Season/Crop	3 SDI lines/ 80"bed high-freq. irrigation	1 SDI line/40"bed low-freq. irrigation	3 SDI lines/80" bed low-freq. irrigation	1 SDI line/40" bed low-freq. irrigation	Flood
1/broccoli	919	977	941	888	869
2/watermelon	1475	976	797	183	-130
3/broccoli	150	-36	164	120	220
4/broccoli	924	752	567	1022	323
5/watermelon	906	741	-112	-86	-561
Total	4374	3410	2357	2108	740

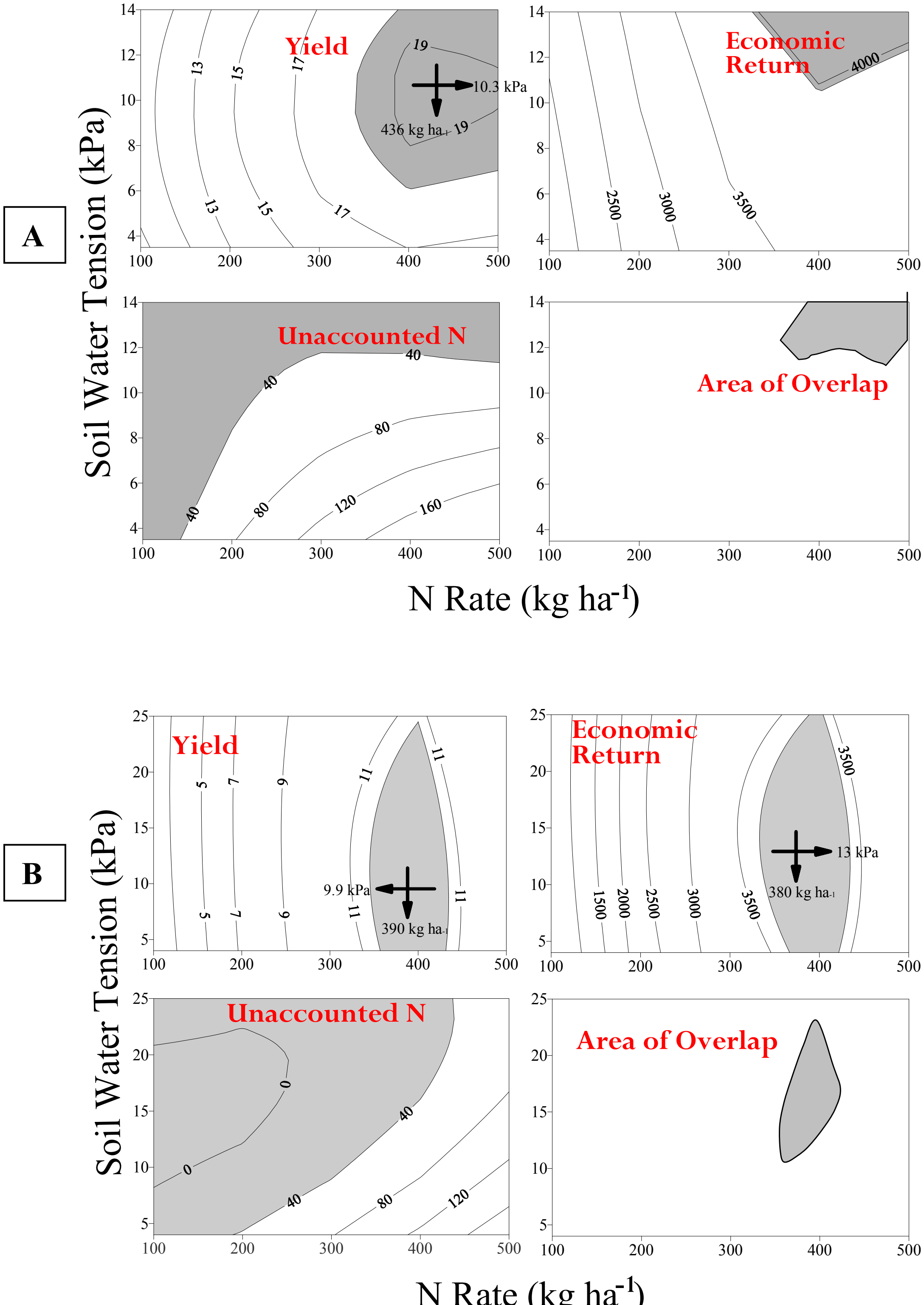

Figure 1. Spatial analysis of agronomic, economic, and environmental outcomes of broccoli production with subsurface drip irrigation during 1994-95 (A) and 1995-96 (B). These figures were originally published in Soil Science Society of America Journal 66:178-185 (Thompson et al., 2002). Used with permission.

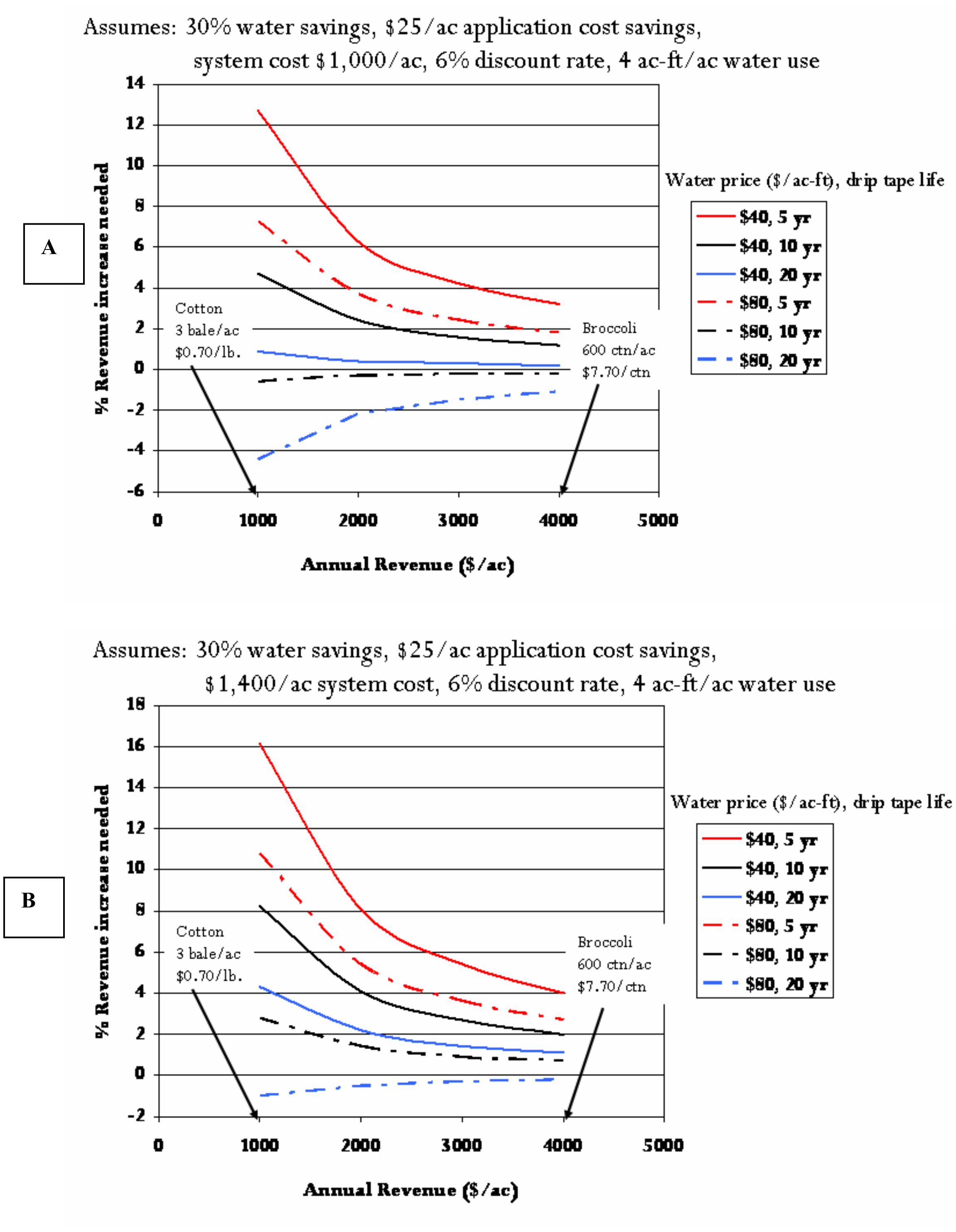

Figure 2. Revenue increase needed with SDI as a function of annual revenue for SDI systems costing $1,000/ac (A), and $1,400/ac (B). The SDI costs are paid for with water and application cost savings.

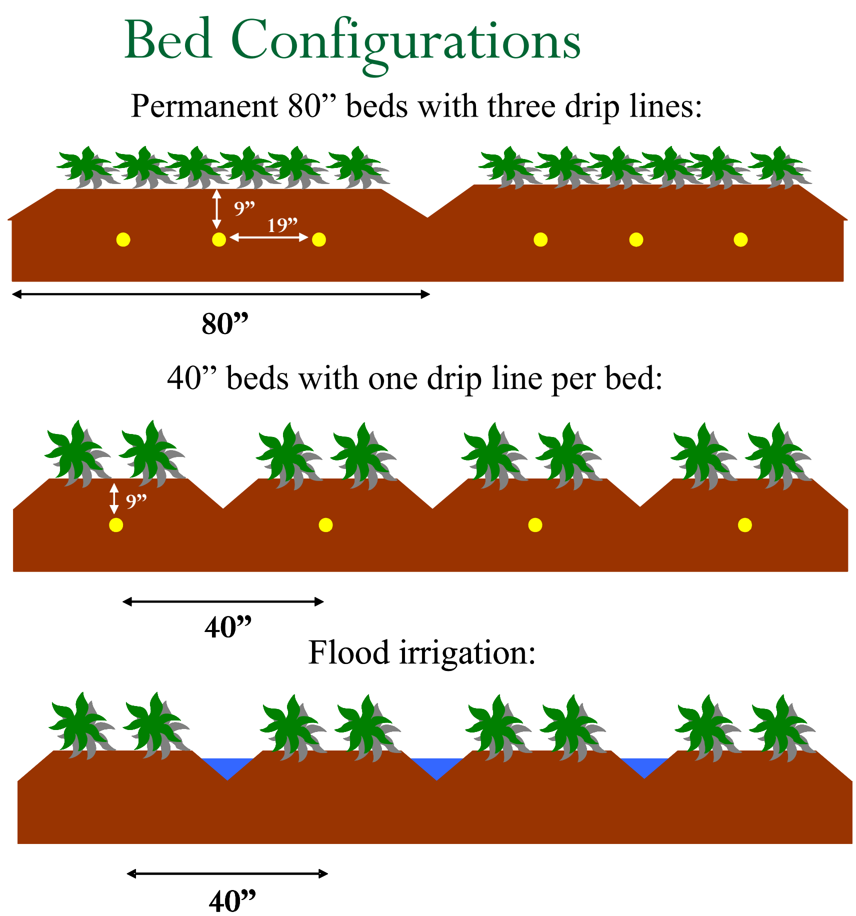

Figure 3 Bed configurations of the long-term ‘AZdrip’ SDI sustainability demonstration project.

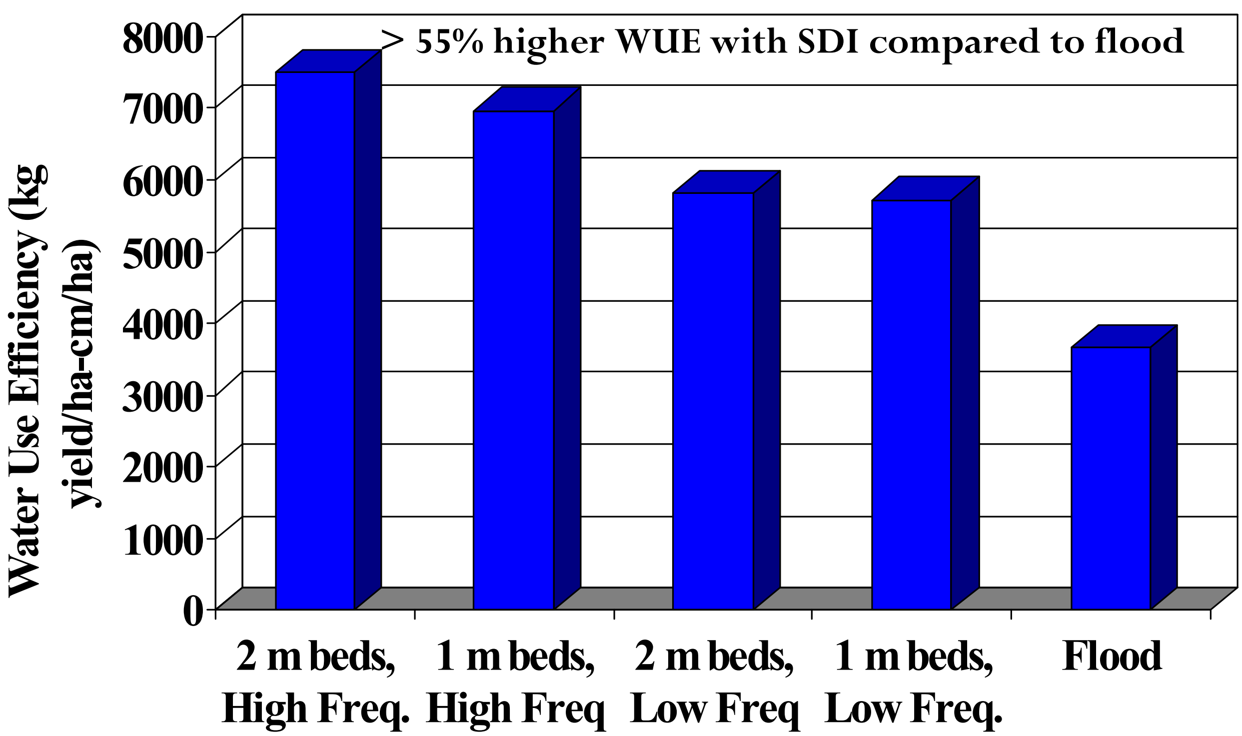

Figure 4. Cumulative water-use efficiency (through five cropping seasons) in the 'AZdrip' SDI sustainability demonstration project.

INDICATORS FOR SUSTAINABLE WHOLE-SYSTEMS: THE PERFORMANCE MEASURES THAT MATTER

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Abstract
How do you evaluate sustainability performance, and build systems to drive performance toward environmental, economic, and strategic goals? This workshop helps teams develop performance metrics and provides a framework to support better decision making. Attendees will identify indicators for sustainable agriculture, identify where and how to collect performance data, outline an approach to determine where and how to improve, and decide what tools to use to support the effort. This interactive session will attempt to answer the following questions: What are the major aspects of agricultural sustainability? What data exists to track performance and impacts?

Key words: sustainability, indicators, performance, improvement

THE LODI RULES FOR SUSTAINABLE WINEGROWING: THE FIRST REGIONAL SUSTAINABLE FARMING CERTIFICATION IN CALIFORNIA

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Abstract

The Lodi Rules for Sustainable Winegrowing are California's first sustainable winegrowing standards that have been peer reviewed by scientists, academics, and environmentalists. They are being implemented on a region-wide basis. The Lodi Rules are based on the Lodi Winegrower's Workbook and are designed to lead to measurable improvements in environmental health of the surrounding ecosystem, society-at-large, and wine quality. Participating growers can get their vineyards certified as producing sustainably grown winegrapes. The Lodi Rules Program requires growers to use a wide range of sustainable practices that result in continual improvement of all aspects of their farming operations. The program is third-party certified by Protected Harvest. The Lodi Rules Program has two components: sustainable winegrowing standards and a pesticide environmental assessment system (PEAS) that measures the environmental impact of all the pesticides, whether organic or synthetic, used in a vineyard during the year. To qualify for certification, a vineyard must achieve a minimum number of sustainable farming practices points and not exceed a maximum number of pesticide impact points calculated using PEAS. Certification is awarded to an individual vineyard on an annual basis. Protected Harvest ensures compliance and chain of custody with the Lodi Rules using an auditing process.

Key words: sustainable agriculture, market-based incentives, certification, Lodi, winegrapes

CALIFORNIA'S SUSTAINABLE WINEGROWING PROGRAM (SWP): KEY ELEMENTS OF SUCCESS AND LESSONS LEARNED

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Abstract
The Code of Sustainable Winegrowing Practices was initiated by members of California's winegrowing community in 2002 to promote sustainable practices for growing grapes and producing wine throughout the state. This comprehensive program provides an illustration of a successful approach to increase adoption of environmental stewardship and resource conservation practices. The SWP code includes education, outreach, and demonstration about innovative sustainable winegrowing practices, from soil and water management in vineyards to materials, waste, and energy management in wineries. More than 1200 growers and 50 wineries have participated in SWP and have submitted self-assessment data which enables benchmarking and tracking of their practices. In this presentation, we will summarize the main program activities, average results, and elements of success. An important feature of the SWP code is that it is collaborative in nature, involving coordination among several organizations and companies in the wine community, regional associations, scientists, government agencies, and non-profit organizations. This participatory approach enables fruitful exchange of knowledge and can increase adoption of sustainable practices. SWP are also using a whole-systems approach, supporting adoption of methods with multiple environmental, economic, and social benefits. Lessons from SWP may be useful for other agricultural sectors, environmental managers, and/or conservation planners.

Key words: sustainable practices, resources conservation, winegrowing, whole-systems approach

SALINITY AND SUSTAINABILITY IN THE SAN JOAQUIN VALLEY

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Abstract
Irrigated agriculture in the San Joaquin Valley is extraordinarily adaptive. This is especially true in the western portions of the valley that have significant areas of saline-sodic soils, a shortage of irrigation water, and no outlet for accumulated subsurface drainage water high in total salts and natural elements that potentially adversely impact the environment and/or the sustainability of agriculture. Recent adaptations include, but are not limited to (1) economical reversion to winter rain-fed cropland in soil areas previously impacted by poor internal drainage, (2) experimentation and investment in "integrated on-farm drainage management" on some of those same drainage-impacted areas which involves managing subsurface drainage water reuse to a point the last drainage water component can be converted to dry salt in evaporators (no ponds), and (3) re-intensification of production by using the best westside soils for profit-making permanent crops in combination with precision water-application systems for conservation of scarce water resources. End result of these actions is the gross agricultural output and returns of the San Joaquin Valley are still increasing and continue to exceed the output of most states and many nations. Several issues still loom large over these successes and continue to threaten agricultural sustainability. They include (1) potentially permanent detrimental soil chemical changes such as boron accumulation in areas re-cycling subsurface drainage water; (2) increasing chemical and salt concentrations in the entire lithologic water column, which continues to migrate and threaten deeper and adjacent subsurface water bodies of better quality; and (3) current regulatory schemes that focus on operators who take action to remove drainage water and salt and store them in surface facilities while there is no scheme to address the longer term threat of the large saline body threatening sustainability of the regional water resources for any economical use, including agricultural, domestic, or industrial supply. With the rapidly increasing urbanization of the eastern San Joaquin Valley, the ongoing adaptive ability of the Westside Valley areas to grow "what you want, when you want it" (except tropicals) will be the future dominant loci of agricultural productivity in the valley and therefore needs to have sustainable salt-management strategies that can be implemented technically and institutionally.

Key words: salinity, subsurface drainage, sustainability, boron

IS DRIP IRRIGATION A SUSTAINABLE PRACTICE IN THE SALINE SOILS OF THE SAN JOAQUIN VALLEY OF CALIFORNIA?

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Abstract

Saline soils due to shallow, saline groundwater conditions occur in the San Joaquin Valley. Because no feasible drainage water disposal facilities exist, artificial drainage is not an option, and thus, improved irrigation practices such as drip irrigation must be used to cope with the salinity. The response of processing tomatoes to subsurface drip irrigation under shallow, saline groundwater conditions (0.6 to 2 m deep; ECgw: 7 to 16 dS/m) was evaluated. At three fields, drip irrigation was compared with sprinkler irrigation. The effect of different water applications on tomato yield was also investigated using a randomized block experiment design. Crop yield and quality, soil salinity, soil-water content, water table depth, irrigation and ground-water salinity, canopy coverage, and crop evapotranspiration were determined. Subsurface drip irrigation of processing tomatoes was highly profitable under these conditions. Tomato yield decreased with decreasing water applications. A water balance showed little field-wide leaching, but localized leaching occurred around the drip lines. Thus, drip irrigation may be a sustainable practice provided seasonal water applications are about equal to seasonal crop evapotranspiration, leaching of salts above the buried drip line occurs, and irrigation water salinity does not exceed about 1.0 dS/m.

Key words: drip irrigation, salinity, tomato

MANAGING SALINITY TO IMPLEMENT VEGETATIVE DUST CONTROL ON THE SALINE OWENS LAKE PLAYA

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Abstract

The Owens Dry Lake Playa is the leading source of dust (PM_{10}) emissions in the United States. In 1997, the Los Angeles Department of Water and Power (LADWP) committed to control dust emissions from the playa surface. One dust control measure that has since been employed is irrigated, native saltgrass (*Distichlis spicata*), termed “managed vegetation.” This measure currently requires saltgrass cover on 50 percent of the surface. The LADWP, working with CH2M HILL and other contractors, designed, permitted, constructed, and is now operating managed vegetation on 3.53 square miles of playa surface. Numerous innovations were required to construct this one-of-a kind facility. Reclamation and irrigation had to be managed to account for saline-sodic soils ($EC_e > 100$ dS/m) and diverse soil textures ranging from sand to expansive clay that is vulnerable to dispersion and sealing. Other major impediments to vegetation of the playa included arid climate, saline shallow groundwater, poor drainage, low-bearing-capacity soils (bulk densities < 0.9 g/cm^3), presence of special-status bird species, and lack of commercial seed supply. Performance data show that this dust control measure is not only effective, but requires vegetative cover percentages much lower than the original 50 percent target.

Key words: arid, playa, salinity, dust control, land stabilization

DEVELOPMENT OF SALINITY MANAGEMENT PLAN FOR CALIFORNIA'S CENTRAL VALLEY

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Abstract

Salinity threatens the economic and environmental viability of California's water resources. The Central Valley Regional Water Quality Control Board is taking a leadership role in development of a comprehensive and sustainable salinity management plan for the Central Valley of California. Key to Central Valley water resources are the Sacramento and San Joaquin Rivers and their confluence in the Sacramento-San Joaquin River Delta. The Sacramento and San Joaquin Rivers and the Delta provide drinking water to two-thirds of the state's population and water supply for agricultural areas throughout the Central Valley, in the Delta, and beyond. The salt-management plan will describe a comprehensive salinity control policy that provides clear direction to interested parties, and describes application of the regional board's regulatory authority to protect water users and prevent long-term degradation of the waters of the state in order to assure its economic viability. Framework for development of this multi-year effort to develop a salt-management plan includes a preliminary accounting of salinity sources, assessment of impacts to beneficial uses of water, assessment of the impacts of regulation on agriculture and industry, economic analysis, review of available salinity treatment and disposal technologies, and summary of previous salinity management efforts.

Key words: salinity, management, regulation, sustainability

KEYNOTE ADDRESS AND CAPSTONE PRESENTATION

Keynote Address

A PARTICIPANT'S PERSPECTIVE ON SUSTAINABLE AGRICULTURE; PAST, PRESENT AND FUTURE

Richard E. Rominger, former U.S. Deputy Secretary of Agriculture and Keynote Speaker

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We've come a long way since we got on the chemical pest control track shortly after World War II with the advent of DDT, but we have along way to go yet.

Here in California an early success in biological control occurred in the 1880s with the introduction of the vedalia beetle into Southern California citrus groves for the control of cottony cushion scale. But it wasn't until 1959 that University of California (UC) researchers Robert van den Bosch, Kenneth Hagen, Ray Smith and Vernon Stem published the seminal article entitled "The Integrated Control Concept." You might say this was the beginning of Integrated Pest Management (IPM). With the publication of Rachael Carson's "Silent Spring" in 1962, the public became more aware of the consequences of the use of chemical pesticides, and more effort went into looking for alternatives. But it was slow going. The chemical companies were funding research to boost their products and convincing farmers that they were the best solution. It wasn't until 1972 that the National Science Foundation (NSF) initiated a research program with the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA), which provided funds for researchers.

In 1972 the California Department of Food and Agriculture (CDFA) began licensing pest control advisors (PCAs), and requiring growers to obtain a recommendation from a state licensed PCA to use a restricted pesticide. Then in 1976 the California Attorney General ruled that the use of a pesticide by a grower came under the California Environmental Quality Act, and each application would require an environmental impact report. This threw the agricultural community into an uproar, so the Legislature tasked the Department of Food and Agriculture, the agency regulating pesticide use at the time, with developing a program that would be the functional equivalent of CEQA. As it happened, I became the Director of CDFA in March of 1977. What great timing. The Department already had begun an Environmental Assessment of Pesticide Regulatory Programs. To make a long story short, that was the beginning of California's strict pesticide regulatory pro gram. It wasn't easy. I got called some pretty uncomplimentary names in meetings with growers.

Meanwhile, back on the farm, our sons were growing crops and using pesticides like other farmers. They were practicing rudimentary IPM, as my brother and I had been, before I came to CDFA. They were acutely aware that with me in Sacramento, if they screwed up, someone would notice. Researchers who wanted to do more work on environmentally friendly alternatives had been having trouble getting funds, so a group of four department chairmen at UC Berkeley in 1977 put together a "Proposal to Develop a University-wide Program in Integrated Pest Management." The Vice President for Agriculture and Natural Resources took their advice and appointed a committee to develop and implement such a proposal. When the committee brought their report to the VP, he indicated agreement with the report, but deemed it was not the right time to move forward to get funding. Those who supported the report, including the Dean Charles Hess of the College of Agriculture at UC Davis, went outside the University to get support. When they came to us at CDFA, we took it to Governor Jerry Brown, and he was convinced that it should be included in the University's budget request. It was, and on July 1, 1979, the State provided funds to UC for IPM research. By this time, however, Professor van den Bosch had become disillusioned and frustrated, and wrote the book “The Pesticide Conspiracy." But Research results began to grow and included crop specific IPM manuals. Here's one for Small Grains that just happens to have a photo of wheat harvest on the Rominger farm. Thirteen years later, the UC Division of Agriculture and Natural Resources under VP Ken Farrell published “Beyond Pesticides, Biological Approaches to Pest Management in California,” which spelled out the areas of needed research. With the current statewide IPM program, the work of researchers and growers continues. I'm indebted to Jim Lyons of UC Davis for refreshing my memory of these events in his “History of the UC IPM Program.”

There's much more to sustainability, of course, than just pest management. If we look at the history of agriculture on this planet, we know what happened. W.C. Lowdermilk of the U. S. Soil Conservation Service, as a result of his studies and travels in 1918 and 1939, described that history in “Conquest of the Land Through 7000 Years.” Another good book on the subject is “Topsoil and Civilization,” written in 1955 and updated in 1974, by Vernon

Gill Carter, a conservation educator with the National Wildlife Federation, and Tom Dale of the U.S. Soil Conservation Service. Both books describe the results of cutting down forests, overgrazing hillsides, soil erosion, siltation, and salinazation. These problems are more recently detailed in Jared Diamond's book "Collapse." We have the technical knowledge, but are we adequately addressing the problems? We may not have as much soil erosion today in California, but we still have runoff impairing water quality, air pollution from our industrialized, mechanized, mobile society, and loss of biodiversity.

Our rapidly increasing population in California, at third world rates, has produced urban sprawl, with increasing competition for land and water, and adding to our traffic congestion, air pollution, and loss of biodiversity. We need land use policies- conservation easements, stronger zoning ordinances, regulations, and market incentives- to absorb most of this population increase within the current footprint of our cities, with infill and higher densities. More and more communities are realizing this, but the pressure from developers is hard for local officials to resist. There should be incentives for developers to build up, instead of out. Elevators are efficient transportation, and handicap accessible too. Our land use has to be more efficient.

We've been talking about the sustainability of our natural resources, our environment. The other two legs of sustainability, economic viability and social responsibility, are equally important. For the food system to be sustainable, everyone in the chain, from input suppliers to producers, workers, distributors, and retailers has to make at least a living wage.

Many people, agencies and organizations are working on improving sustainability. I'll mention some that I'm aware of, and in many case involved in. CDFA, along with USDA, has responsibilities for pest and disease prevention, detection and eradication, which requires adequate funding. The Natural Resources Conservation Service (NRCS) operates several conservation programs - the Environmental Qualities Incentives Program (EQIP), the Wetlands Reserve Program (WRP), the Wildlife Habitat Incentives Program (WHIP), the Conservation Reserve Program (CRP), the Grasslands Reserve Program (GRP), and the newer Farm and Ranchland Conservation Program (FRCP), and Conservation Security Program (CSP). There could be some improvements and consolidation in the older programs and the newer ones need to be greatly expanded. The technical assistance needed to implement these programs needs to be adequately funded. We need a much larger investment in these programs in the next Farm Bill. Their possibilities were envisioned in a 1996 NRCS publication, “America's Private Land, A Geography of Hope.”

A private, non-profit, 501(c)3 organization, Sustainable Conservation, is working with dairymen to convert dairy waste into energy, and with farmers and ranchers and government agencies to streamline the application and permitting process for conservation programs and practices. The Roots of Change Council is working to implement “The New Mainstream” to improve the sustainability of the food and farming systems in California. The American Farmland Trust is working on federal farm policy to improve stewardship of America's private lands, and with state and local governments and local land trusts to prevent much of our best soils from being converted to non-agricultural uses. A new company, Marrone Organic Innovations, is seeking to discover and develop effective natural products for pest and weed control.

The Environmental Protection Agency announced last week that they are recommending limits on thousands of uses of pesticides because of their adverse effects on public health. This is the result of the completion of a ten year review, ordered by Congress, of pesticide chemicals, following the passage of the Food Quality Protection Act (FQPA). During the first years of this review, I co-chaired, with the Deputy Administrators of EPA, the 50-person stakeholder advisory committee working with EPA and USDA. I'm pleased to see there are finally some results. However, I'm sure the health and environmental communities will think the recommendations don't go far enough, and the agri-chemical community will think they go too far. But at least it's progress in the right direction.

The EPA also has responsibilities for the implementation of the Clean Water Act and the Clean Air Act. California agencies are also involved through the State Water Resources Control Board and the Air Resources Board and their regional boards. Agricultural practices are now under the scrutiny of these agencies.

None of these are easy issues. So how do we continue to move the ball forward? We pride ourselves in California and the U.S. for being out in front. But, in some areas other countries have equaled or surpassed us. We need to start by working together to find solutions on the issues on which we agree, and not spend too much time on the areas where we disagree. That's a first, logical step.

We need to think partnerships, public and private cooperation and collaboration, as exemplified by some of the examples mentioned above, not forgetting the three bases of sustainability - economic, environmental and social. It means finding solutions where everyone wins. We should look for ways to lower the barriers to change and acceptance.

This means more investment, public and private, in research to find more effective, environmentally friendly pest and disease controls; more conserving farming practices that prevent soil erosion and water and air pollution; more energy efficient machinery, buildings and vehicles; carbon sequestration; more efficient technologies for converting agricultural wastes into energy, both electricity and bio-fuels; and with the sequencing of more crop and animal genes, the continuing development and use of bio-engineering techniques that provide new breakthroughs, especially in techniques that do not use the more controversial trans-genic methods.

It means aligning regulatory programs with performance standards for growers. These regulatory programs should provide incentives for growers to meet specified standards, such as those in the Dairy Quality Assurance Program or the Wine Industry Sustainable Practices. Change is happening and the agricultural community should be at the table, not hanging back trying to impede change. Growers and regulators working together to develop agreed upon standards should be a win for both.

It means working at the state and federal levels to secure legislation providing policies and funds that foster sustainability in conservation and commodity programs; risk management programs; marketing, including local and regional markets and direct farmer to consumer channels; nutrition; food safety; energy; rural development; research; pest exclusion, detection and eradication; and carbon credits trading, to name the most obvious.

It means educating more consumers about how their decisions in food purchasing affect their health, the safety and security of their food supply, the structure of the food system, and ultimately, the environment in which we all live. We need to foster a deeper connection between consumers and the land from which their food comes. As Aldo Leopold said in 1948 in his book, “A Sand County Almanac,” “When we see land as a community to which we belong, we may begin to use it with love and respect. There is no other way for land to survive the impact of mechanized man, nor for us to reap from it the esthetic harvest it is capable, under science, of contributing to culture. That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics. That land yields a cultural harvest is a fact long known, but latterly often forgotten." Or as John Muir said, "When we try to pick out something by itself, we find it hitched to everything else in the Universe."

Global warming is affecting all of us, and we all need to be part of the solution. At this point, I think we in the U.S. are falling short. The huge amount of human, physical and monetary resources being consumed by war is adding to the strain we all feel. In the long term, the sustainability of California agriculture will depend on the sustainability of the entire planet. Our goal is healthy farms, healthy people, healthy communities and a healthy eco-system. We should settle for nothing less.

Capstone Presentation

MEASURING THE IMPACTS OF AN EXPERIMENT IN SUSTAINABILITY

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Abstract

As the Western Sustainable Agriculture Research and Education (SARE) program, edges toward its 20th anniversary, it becomes instructive to reflect both informally and formally on how much ground the program has covered. SARE was initiated in 1988 as part of the U.S. Department of Agriculture's Cooperative State Research, Education, and Extension Service to fund competitive grants supporting agricultural systems that are economically, environmentally, and socially sound. Western SARE, one of four SARE regions, is administered at Utah State University under regional coordinator Dr. Phil Rasmussen, while its professional development is administered as a subcontract under the University of Wyoming and the National Center for Appropriate Technology, a nonprofit organization based in Montana. Western SARE has disbursed nearly $35 million to fund grants in three primary areas: research and education, farmer/rancher, and professional development. As this experiment in sustaining sustainability has matured, Western SARE has conducted surveys gauging the reach and impacts of its professional development program (2004) and its farmer/rancher grants (2005). Both surveys indicate that the concepts of sustainability and their on-the-ground application are gaining considerable traction. To round out the picture, Western SARE is embarking on a survey of its research and education grant recipients to determine whether the current course of research is meeting the needs of the western agricultural producers and their support teams. These critical milepost surveys will help chart the course of Western SARE–whether it's "on course" or in need of corrections. In all cases, Western SARE endeavors to view sustainability in the broader view -- including both on and off-farm impacts.

Key words: sustainable agriculture, Sustainable Agriculture Research and Education (SARE) program

POSTER MANUSCRIPTS

ENVIRONMENTAL MANAGEMENT AND SUSTAINABILITY IN THIS GLOBAL AGE

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Abstract

Agricultural biosecurity, environmental management, and agricultural practices are interrelated. Good environmental management is important for agriculture locally, nationally, and globally. We live in an age when an infectious agent that develops in one part of the world becomes a global concern. If everyone can work cooperatively to develop good environmental management systems, this may help to prevent outbreaks. There is also a need to quickly address any problems that develop so that they are under control. The National Agricultural Biosecurity Center, the Geographic Information Science and Spatial Analysis Laboratory, and the Center for Hazardous Substance Research at Kansas State University are working with others to develop methods and technologies to advance this effort. This contribution will describe some of the work that is in progress.

Key words: environmental management, agricultural biosecurity, cooperation

Introduction

Agriculture is very important in all parts of the world because food is essential for life. In a sustainable world, production agriculture is also an important source of raw materials for many other products as well. Good environmental management in agriculture is necessary and desirable because of the need for effective pest management, good air and water quality, and appropriate resource management.

Environmental Management Systems

The environmental management systems (EMS) that are commonly used by industrial firms (ISO, 2004) have been extended to agricultural operations and used for environmental management in agriculture. Most of these systems make use of the plan, , which is designed to promote continual improvement of the EMS (U.S. EPA, 2006). In sustainable agriculture, the production management plan can be combined with the EMS to have an integrated EMS that includes economic, environmental, and social aspects that affect the triple bottom-line goals of economic profitability, environmental quality, and social betterment (Beloff et al., 2005).

Because pathogenic organisms and other pests can impact agriculture negatively, there is significant value in having good environmental management in all parts of the world. The Internet provides an opportunity to make information available at a very low cost to all who are able to connect to this great information resource. The Internet can be used to provide basic information that is needed for effective environmental management as well as more comprehensive information that enables users to find the sources they need to make good decisions (U.S. EPA, 2006; University of Wisconsin, 2006).

The Environmental Knowledge and Assessment Tool (EKAT) (Apte et al., 2005) is an example of a resource that is available through the Internet (www.ekat-tool.com). In this example, the EKAT team has found useful environmental information that is available on the Internet and organized it to allow EKAT to be used as an information resource. In addition, several tools have been developed to help with environmental compliance, research, and decision making. Better decisions can be made when appropriate environmental information is available.

The Internet has become a useful repository for information that is of importance in agriculture. Some of the data is available within a geographic information system (GIS) database; soil type, nutrient concentrations, and pH can be available for a farm with data that varies with geographical position. Information on locations of known pests can also be presented and stored using GIS. Global positioning systems (GPS) allow the user to relate positions in a field to those stored in a GIS repository. The combined use of GIS and GPS enables producers to use raw materials efficiently and also have excellent yields. Finding the needed information for good decision making is made easier because of EKAT, GIS, and GPS.

Benefits of a comprehensive EMS include better environmental performance, documented environmental records, reduced health risks, and effective regulatory compliance. Key elements of an effective EMS include an environmental policy statement; description of environmental aspects; listing of environmental requirements; clear environmental goals; description of the environmental management program; well-defined structure and responsibility; appropriate education and training of employees; effective communication and documentation plans; appropriate documentation; operational management, and control; regular monitoring and measurement of performance; plans to address emergencies and non-conformance; good records management; and regular audit and review (U.E. EPA, 2006; University of Wisconsin, 2006).

Transparency and open communication have societal benefits because others can learn by reviewing the experiences and results that have been reported. This is especially important as efforts are made to incorporate sustainability into an EMS that is designed to serve the needs of an agricultural producer.

Voluntary development of an environmental management system may have significant value to both the producer and society; however, financial rewards from the government for the development and implementation of an EMS can provide additional incentive to develop and make use of an EMS. Efforts to extend good environmental management to all countries of the world will require financial aid and effective communication. There are sufficient benefits for all citizens of the world to justify greater expenditures on environmental management in agriculture and for basic sanitation.

Agricultural Biosecurity

There is a need to maintain and sustain agricultural production systems and food processing operations. Increasing levels of trade and travel have escalated the spread of plant and animal pests and diseases. New methods of ensuring agricultural biosecurity are needed to counter the direct animal, plant, and human effects of the introduction of these foreign pests and diseases and the potentially devastating economic ramifications that result. These methods include more sophisticated and complete disease surveillance systems, disease response and control strategies, and well-planned recovery efforts. Kansas State University has an ongoing agricultural biosecurity program (http://nabc.ksu.edu) and research in food safety and security (http://fss.k-state.edu). Recent work related to biosecurity includes a comprehensive review of mass carcass disposal that may be necessary in the event of an animal disease outbreak (Nutsch et al., 2004). Food safety studies include work in food microbiology (Bohra et al., 2001; Danler et al., 2003; Oberst et al., 2003; Retzlaff et al., 2004 and 2005; Singh et al., 2005a and 2005b; Thippareddi et al, 2003; and Wu et al, 2004a and 2004b).

There is a continuing need for advances in food safety in food processing operations where pathogenic microorganisms may be present. New facilities are now in place at Kansas State University to conduct research with pathogens in biologically secure laboratories.

Conclusions

Environmental management systems, which are now widely used in industry, can be extended to agricultural operations. Progress in environmental management and sanitation leads to better health and welfare. The time is right to provide support and incentives to encourage development and use of environmental management systems in agriculture.

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SOIL-WATER AND NUTRIENT MANAGEMENT FOR MAIZE UNDER VARIED IRRIGATION AND ORGANIC-INORAGANIC FERTILIZER MIXTURES IN MALAWI

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Abstract

Maize (Zea mays) irrigation research was conducted at Kasinthula Research Station and Domasi Irrigation Scheme in Malawi to evaluate the effects of organic and inorganic fertilizer on maize performance, water-use efficiency (WUE), and nitrogen-use efficiency (NUE) under different irrigation frequencies. The aim was to define their optimum combination for proper soil-water and nutrient management that can simultaneously solve drought and low soil fertility constraints in Malawi. Maize variety DK 8031 was planted on ridges spaced at 0.75 m between rows and 0.25 m within rows. It was a split-plot design with four irrigation frequencies at Kasinthula as main plots: depletion irrigation at 40% of the soil-water content available to the crop, and 40 mm every three to four days, seven days, and 14 days. At Domasi, three irrigation frequencies were used as follows: once a fortnight, once every four weeks, and once every six weeks. Nitrogen sourced from compost (C), farmyard manure (FYM), urea (U) and their mixtures urea(2)compost(1), urea(1)compost(2), urea(2)FYM(1), and urea(1)FYM(2) were sub-plots. Organic manure was banded three weeks before planting. Soil properties, climate, and grain yields data were measured and subjected to ANOVA and regression analysis using Genstat. With the long irrigation frequency (40 mm every 14 days for winter and 60% depletion for summer), the greatest yield and WUE occurred in the sole urea treatment. WUE and NUE were lowest in sole organic N sources in all irrigations. Yield and NUE increased with high urea ratio in combination of the two organic nitrogen sources and increased irrigation frequency. WUE decreased with irrigation frequency increase. Grain yield results observed on this experiment in winter 2003 were lower compared to the optimum maize grain yield at the station in previous years due to termites, irrigation water sharing, and soil compaction problems. These results indicate that in times of water shortage, sole urea can be more readily utilized than recently applied organic nitrogen sources. With adequate water, combined organic N and urea can provide sufficient N release.

Key words: Malawi, irrigation schemes, urea

Introduction

In Malawi, maize (Zea mays) is the most important food crop with an annual average per capita utilization of 179 kg (CIMMYT, 1992). It occupies 70% of the total arable land with more than 1.6 million ha (Malawi Government and FAO report, 2003).

Despite high-yielding varieties that have been released and recommended for small-holder farmers and its high adoption rate, maize production levels in Malawi remains low

(Kalonga Stambuli, 2002). The 2002/2003 maize estimates in Malawi by FAO reported yields of 1.86, 1.85, and 1.21 t ha^{-1} for small-holder winter maize, estate and small-holder summer maize production, respectively (Josser and Lewis, 2003). These yields were low relative to the expected yields despite the reported 200% and 100% increase in use of high-yielding seed and fertilizer as compared to late 1970/80s. Matarira (1995) indicated that the reasons for this were drought, high temperatures, and soil fertility decline on most small-holders' rain-fed fields. This decline in fertility is due to intensive cropping systems and presence of soils that easily leach (Green and Nanthambwe, 1992) and the increase in nitrogen fertilizer prices in the past 10 years due to removal of subsidies (Kalonga Stambuli, 2002). A solution is needed that develops technologies that optimize the efficient use of the limited water and soil resources to achieve sustainable agricultural production (Sivakumar and Wallace, 1991) because soils in the Sub-Saharan region are structurally degraded and nutrient depleted (Morin, 1993). It is envisaged that integration of irrigation and sustainable sources of N in Malawi may achieve a sustainable maize production goal. Hence in Malawi, it is important to define optimum combinations of soil-water and nutrient management. The potential of irrigated fields should be fully utilized by using alternative sources of nitrogen (N) that are sustainable and affordable, so as to maintain the soil production capacity of the irrigated fields over time. This sustainability supports the government of Malawi advocacy on maize production improvement through irrigation and use of low-cost soil-improvement strategies. However, there has been minimal research on determining the optimum soil-water and nutrient-management regime for irrigated maize. This project aimed-

- to evaluate the impact of organic and inorganic fertilizers on irrigated maize; and
- to compare the effect of the two and their mixtures on maize water-use efficiency (WUE), nitrogen-use efficiency (NUE), and soil \-water content using existing field experiments data from the Kasinthula research station in Malawi.

  It is planned that the results will assist in providing information for proper soil-water and nutrient management for small-holder farmers in Malawi and other Sub-Saharan countries.

  The specific objectives of the project were-

- to determine the effect of irrigation frequency and nitrogen source on soil-moisture content in irrigated maize;
- to determine the effect of compost, farmyard manure, and inorganic fertilizer application on maize performance, maize water-use efficiency, and maize yield response to nitrogen; and
- to determine the optimum amount of organic manure and inorganic fertilizer combination for irrigated maize.

Materials and Methods

2.1 Site description

2.1.1 Site location

The field experiment was conducted at Kasinthula Research Station situated 5 km south of Chikwawa district (Figure 2.1) in Malawi. Kasinthula Research Station (16º0'S, 34º5' E) is situated in the floor of the Great Rift Valley on 200 m altitude.

2.1.2 Climate

There are distinct winter and summer seasons at the site. Winter is from May to September, and summer is from October to March. Growing conditions in winter are more favourable for growing most annual crops than in summer when temperatures are excessively high (Table 2.1). Growing period for maize in this low tropical area is always under 135 days (Sakala, 1998). Annual rainfall at the station is in the range of 350 to 750 mm, primarily between November and May (Table 2.1, Figure 2.1). The site receives minimal precipitation in winter followed by high evaporation in early summer.

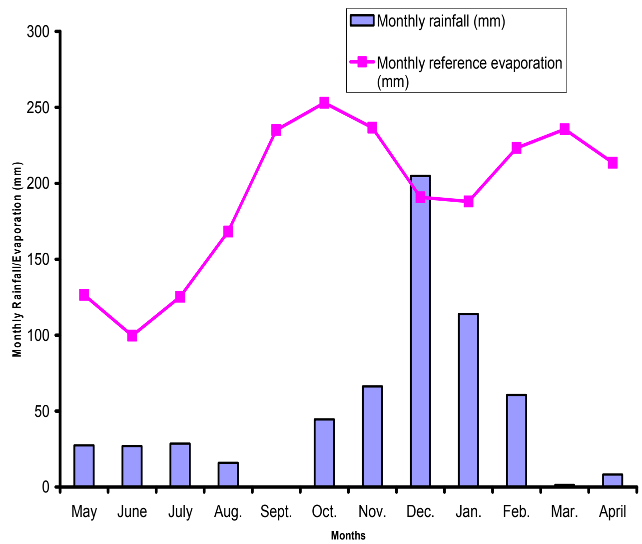
Table 2.1 Average meteorological data for Kasinthula Research Station, from 2003-2005.

Weather Variables	Winter months					Summer months						
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Max. temp (°C)	**32.0**	**29.1**	**26.3**	**30.0**	**33.8**	**36.0**	**36.8**	**35.1**	**32.7**	**32.3**	**32.8**	**33.6**
Min. temp. (◦C)	**18.7**	**18.9**	**14.0**	**14.0**	**18.3**	**21.1**	**23.6**	**24.9**	**24.4**	**23.1**	**16.5**	**17.9**
RH (%)	**68.0**	**68.0**	**73.0**	**63.9**	**71.3**	**65.2**	**67.0**	**67.0**	**79.0**	**77.0**	**72.0**	**69.0**
Wind (km/hr)	**4.8**	**3.3**	**3.69**	**7.4**	**15.2**	**15.7**	**12.3**	**4.0**	**3.0**	**2.9**	**2.7**	**3.4**
Rainfall (mm)	**16.5**	**14.8**	**26.5**	**1.0**	**6.3**	**0.0**	**26.6**	**199**	**329**	**185**	**10.7**	**5.0**
ET (mm)	**6.5**	**5.5**	**4.32**	**5.7**	**7.5**	**9.0**	**9.9**	**5.6**	**5.8**	**5.6**	**6.5**	**7.0**
Sunshine (hrs)	**11.0**	**8.0**	**9.08**	**9.2**	**8.9**	**9.7**	**10.3**	**6.4**	**6.2**	**6.6**	**8.5**	**8.8**
Soil temp. (◦C)	**23.5**	**22.3**	**22.6**	**24.7**	**27.4**	**29.3**	**31.7**	**30.1**	**29.3**	**29.4**	**28.5**	**24.8**
Solar radiation (MJm^{-2}d^{-1}	**18.7**	**18.2**	**17.3**	**17.0**	**20.0**	**24.0**	**24.3**	**20.8**	**22.7**	**22.3**	**23.3**	**24.4**

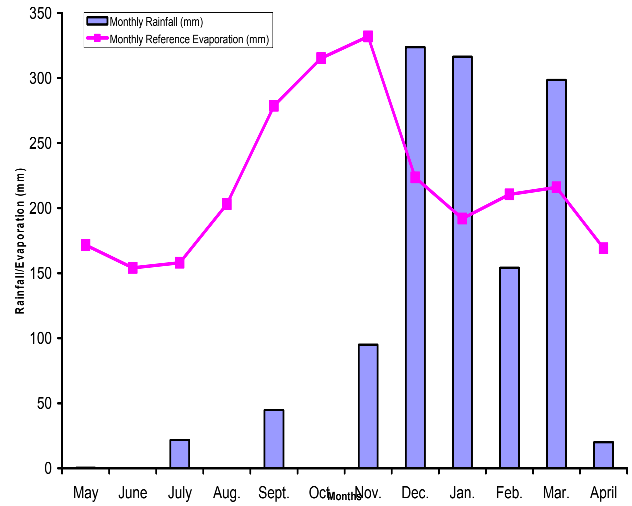
Note: ET is from Pan Evaporation.

2.1.3 Soil

Soils were initially analyzed in terms of physical and chemical soil properties: the average bulk density is 1.7, soil texture is sandy loam; soil pH is 7.4; and organic matter is 0.03%, with 10.5% available water. The soil at Kasinthula is generally sandy loam. The soil is moderately drained with the water table at 2.5 m from the ground surface.



May 2004- April 2005



May, 2003 –April 2004

Figure 2.1 Monthly rainfall and monthly reference evaporation for Kasinthula research station from May 2003-April 2005.

2.2 Field experiment

2.2.1 Experimental design

The experimental design for the field research was a split-plot with four irrigation-frequency treatments as main plots (Table 2.2), and seven sources of nitrogen formed the sub-plot treatments.

Maize of DK 8031 variety was planted on ridges spaced at 0.75 m between ridges and 0.25 m between plants within rows with one seed per station. The plot sizes were 10 ridges (7.5m * 20 m gross) with a net plot of six ridges (4.5 m * 16 m). The experiment was conducted for three winter seasons in 2003, 2004, and 2005.

2.2.2 Nitrogen application

The nitrogen sources were compost (C), farmyard manure (FYM), an inorganic fertilizer from urea (U) and their mixtures in different proportions (Table 2.2) in ratios of urea(2)compost(1), urea(1)compost(2), urea(2)FYM(2), and urea(1) FYM(2). Compost (made from maize stover, grasses, and cattle manure) and farmyard manure (1% N) were applied by a banding method to the ridges three weeks before planting at 10 t ha^{-1} (dry-weight) for sole compost and farmyard manure treatments. Urea fertilizer was applied at the rate of 120 kg N ha^{-1} in two applications and 45 kg P_2O_5 ha^{-1} at basal dressing by dollop method. Basal dressing consisted of 60 kg N ha^{-1} and 45 kg P_2O_5 ha^{-1} one week after germination and was top dressed with 50 kg N ha^{-1} three weeks later. The mixed treatments had organic manure three weeks before planting, followed by urea three weeks after germination.

2.2.3 Water application and irrigation scheduling

Irrigation water was applied in furrows using a gated 15-cm-diameter PVC pipe. Each gate was being set at a flow rate of 0.5 l s^{-1}. The flow rate out of each gate was determined using a bucket and a stop watch. The PVC pipe was being laid at the beginning of the furrows and connected to a concrete line canal in which water was maintained at a constant head above the center of the PVC pipe inlet. Forty mm of gross irrigation was being applied at every irrigation interval.

The main plot was composed of four irrigation frequencies at Kasinthula. One was based on irrigating to field capacity, whenever 40% of the total water available to the crop had been used, i.e. 40% depletion. The other three treatments received water every three to four days, every seven days or every 14 days. The depletion irrigation at 40% treatment was carried out by maintaining a soil-water balance sheet (Barak, 1986).

Depletion Irrigation

The soil-moisture storage was estimated from the available water-holding capacity of 100 mm m^{-1} within the crop root zone. The crop consumptive use (ETc) was computed using pan evaporation multiplied by a pan factor and a Kc value (Appendix sheet 1). The consumptive use was depleted from the available soil-water on a daily basis until the available soil-water reached a maximum allowable soil-water deficit of 40%. The available soil-water was determined by using field capacity, wilting point,, and the maize maximum root zone of 1.2 m.

The water balance equation used in irrigation determination was

$$SWC_i = SWC_{i-1} - ETC_i + I_i + P_i - D_i \quad \text{(Equation 2.1)}$$

where: SWC_i is the soil-water content for a particular day (mm),

SWC_{i-1} is the soil-water content for the previous day (mm),

ETc_i is the crop evapotranspiration (mm),

I_i is the irrigation since previous day (mm),

P_i is the effective precipitation since previous day (mm), and

D_i is the deep percolation, water lost beyond the root zone (mm).

The critical soil-water deficit for the maize (SWD_c) was calculated using Equation 2.2:

$$SWD_c = SWC \times MRZ \times MAD \quad \text{(Equation 2.2)}$$

where:

SWC is the soil-water content or soil-water storage (mm m^{-1}),

MRZ is maximum root zone for maize assumed at a constant of 1.2 (m), and

MAD is maximum allowable soil-water deficit of 40%.

The crop-water use (ETc) was computed from climatic data using the Class A pan-evaporation method for estimating reference crop evapotranpiration on a daily basis. The modified-pan-evaporation equation used was

$$ET_o = K_p E_{pan} \quad \text{(Equation 2.3)}$$

where: ET_o is reference evapotranspiration [mm d^{-1}],

K_p *is* pan coefficient of 0.65 for Class A pan placed in short, green cropped and medium wind area. (Allen et al., 1998), and

E_{pan} is pan evaporation [mm d^{-1}].

The reference evapotranspiration (ET_o) was then multiplied by a crop coefficient at a particular growth stage to determine crop consumptive use at that particular stage of maize growth (Figure 2.3).

$$ET_c = ET_o Kc \quad \text{(Equation 2.4)}$$

The daily ETc was included in Equation 2.1 and when the soil-water storage reached 40% irrigation and was being applied.

Irrigation treatments F2, F3, and F4 were based on applying 40 mm every three to four days, every seven days, or every 14 days to match farmers' real irrigation scheduling in Malawi. There was no use of weather on the three irrigations; however soil-water content was recorded before irrigation.

2.2.3 Water-use efficiency and yield response to Nitrogen

The water input (*W*) in each irrigation treatment was calculated as

$$W = I + R + SWC_i \qquad \text{(Equation 2.5)}$$

where I is irrigation, R is rainfall, and SWC_i is initial soil-water content.

Water-use efficiency (*WUE*) was then calculated by dividing the maize grain yield (kg ha^{-1}) by the amount of irrigation water for that particular treatment in mm.

The yield response to nitrogen was calculated by dividing the grain yield (kg ha^{-1}) by the amount of nitrogen applied in kg, which was 120 kgN ha^{-1} for all treatments.

2.3 Data collection and statistical analysis

Gravimetric soil-moisture measurements were conducted every 14 days and rainfall, temperature, evaporation, solar radiation, wind speed, relative humidity, and sunshine hours were recorded daily. Data on planting date, germination count, date of supplying, days to 50% tasselling, days to 50% silking, stand count at harvest,; plant height at harvest, cob yield, grain yield, seed size or weight, and total amount of water applied up to harvest were all recorded.

Data for the field experiment was analyzed using analysis of variance (ANOVA) by the Genstat computer program based on the split-plot design statistical model (Equation 2.6).

$$¥_{ijk}=\mu+R_i+I_j+RI_{ij}+\beta_k+R\beta_{ik}+I\beta_{jk}+RI\beta_{ijk}+\sum (ijk) \qquad \text{(Equation 2.6)}$$

where: μ is the overall mean;

R_i is the replicate effect;

I_j is irrigation frequency effect;

RI_{ji} is the error due to irrigation and replicate effects;

β_k is Nitrogen source effects;

$I\beta_{jk}$ are error effects due to irrigation and nitrogen sources;

$RI\ \beta_{ijk}$ are error effects due to blocking, irrigation and nitrogen sources; and

$\sum (ijk)$ are error effects due to interaction of factors.

Table 2.2. Field experiment design and treatments.

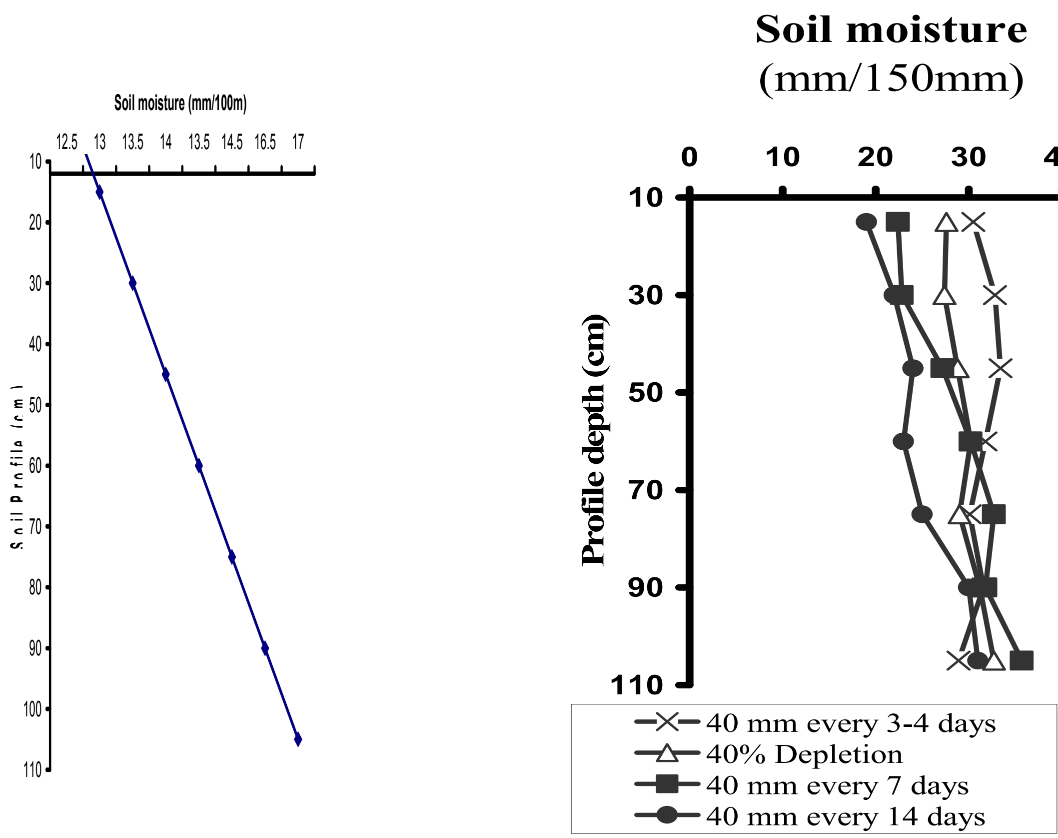
Main plot (Irrigation)	Split-plot treatment (Nitrogen Sources)	N Rate kg/ha and Source		
		FYM	Compost	Urea
	T1=Urea. (U)	0	0	120
F1=40% Depletion level	T2=Compost Manure (C).	0	120	0
	T3=FYM (FYM)	120	0	0
	T4= Compost (2)Urea (1).	0	40	80
	T5=Compost (1)Urea (2).	0	40	80
	T6=FYM (2)Urea (1).	80	0	40
	T7=FYM(1) Urea (2).	40	0	80
F2= 40mm in 7 days.	T1=Urea. (U)	0	0	120
	T2=Compost Manure (C).	0	120	0
	T3=FYM (FYM)	120	0	0
	T4= Compost (2)Urea (1).	0	40	80
	T5=Compost (1)Urea (2).	0	40	80
	T6=FYM (2)Urea (1).	80	0	40
	T7=FYM(1) Urea (2).	40	0	80
F3 = 40mm in three to four days.	T1=Urea. (U)	0	0	120
	T2=Compost Manure (C).	0	120	0
	T3=FYM (FYM)	120	0	0
	T4= Compost (2)Urea (1).	0	40	80
	T5=Compost (1)Urea (2).	0	40	80
	T6=FYM (2)Urea (1).	80	0	40
	T7=FYM(1) Urea (2).	40	0	80
F4= 40mm in 14 days.	T1=Urea. (U)	0	0	120
	T2=Compost Manure (C).	0	120	0
	T3=FYM (FYM)	120	0	0
	T4= Compost (2)Urea (1).	0	40	80
	T5=Compost (1)Urea (2).	0	40	80
	T6=FYM (2)Urea (1).	80	0	40
	T7=FYM(1) Urea (2).	40	0	80

Note: U Sole Urea treatment. C Sole Compost treatment FYM Sole farmyard manure treatment.

Results

3.1 Soil-water content

Irrigating 40 mm every three to four days maintained a high, constant soil moisture in the upper soil profile of 0-60 cm. (Fig. 3.1b)**.** The longest irrigation at 40 mm every 14 days had lowest water storage in the upper profile of 0-60 cm. All irrigation regimes maintained almost the same moisture content at a depth of 90-110 cm (Figure 3.1b).



(a) Initial Soil Moisture content (mm). **(b) Effect of irrigation schedule on profile soil moisture change.**

Figure 3.1. Effect of irrigation frequency on soil-profile moisture content and watertable.

3.2 Crop water use

The potential water supply in each of the four irrigation treatments was determined as the sum of irrigation, rainfall, and change in soil-water content. Throughout the growing period, crop water use under 40 mm every three to four days of irrigation and 40% depletion were above that of calculated *ETc*. The estimated crop water use in the 40 mm every 7 days irrigation and 40 mm every 14 days irrigation treatments were initially above calculated *ETc* and later overtaken by calculated *ETc* at different times (Figure 3.3).

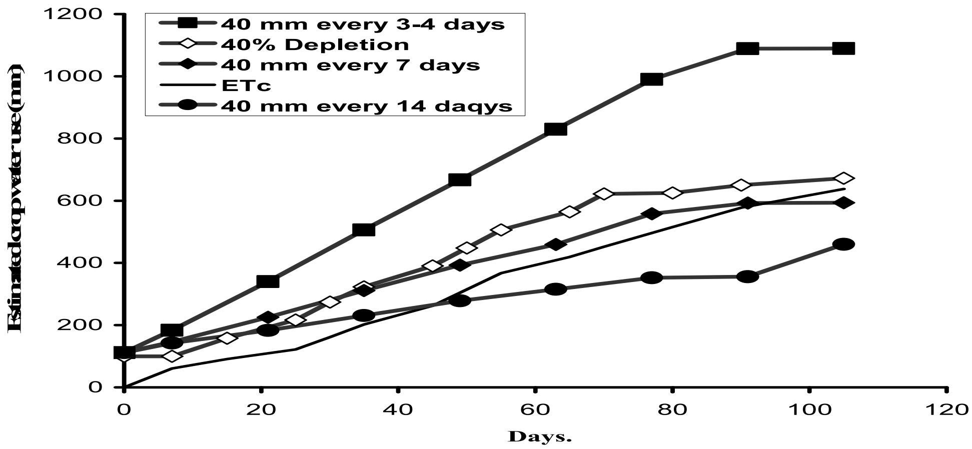


Figure 3.3 Estimated cumulative crop-water uses during the maize growing season (winter).

3.3 Effect of irrigation frequency on Maize yield

Irrigation frequency had a significant effect (P<0.001, P<0.05, P<0.001) on maize grain yield in 2003, 2004, and 2005 respectively. Irrigating 40 mm every three to four days gave the highest mean grain yield of 3.88 t ha^{-1}. The yield from irrigating 40 mm every 7 days and at 40% depletion level was not significantly different (Table 3.1). The lowest grain yield was observed in 40 mm every 14 days of irrigation treatment.

Table 3.1: Effect of irrigation frequency on mean maize yield (t ha^{-1}) from 2003 to 2005 at Kasinthula research station.

	Irrigation Frequencies						
Year	40% Depletion.	40 mm every 7 days.	40 mm every three to four day	40 mm every 14 days.	**CV %**	**Se±**	**Sig.**
2003	3.02	3.06	3.99	1.82	28.2	075	***
2004	3.31	3.13	3.46	2.81	20.6	0.65	*
2005	4.39	4.37	4.19	3.44	20.8	0.85	***
Mean	**3.57**	**3.52**	**3.88**	**2.69**			

Maize grain yields appeared to be linearly correlated with irrigation application (Equations 3.1).

The following mathematical equations were obtained of:

Year	Mathematical equations	
2003	Yield = 0.003 I + 1.0273	(R^2= 0.93)
2004	Yield = 0.009 I + 2.58	(R^2 =0.87)
2005	Yield= 0.008 I + 3.53	(R^2 =0.30)

(Equations 3.1) indicates an overall grain yield increase of 3, 9, and 8 kg $(ha\ mm)^{-1}$ with irrigation increases from 360 mm to 1200 mm in winter 2003, 2004, and 2005, respectively.

3.4 Effect of different nitrogen sources and their combinations on irrigated maize yield

Maize grain yield differed (P<0.001, P<0.01 and P<0.001) in the seven nitrogen sources in 2003, 2004, and 2005, respectively. Mean yield across the seven nitrogen treatments, use of sole urea, and (1)FYM :(2)U and U(2):C(1) treatments had highest grain yields of 4.72, 4.44, and 4.21 t ha^{-1} (Table 3.2), which were not significantly different but were significantly different and greater than results from nitrogen sourced from U(1)C(2) and U(1)FYM(2) treatments. Both also significantly differed with the results from nitrogen sourced from sole compost and farmyard manure which had the lowest grain yield.

Table 3.2: Effect of nitrogen sources and their combinations on maize yield (t ha^{-1}) from 2003 to 2005 at Kasinthula research station.

YEAR	**Urea**	**Compost**	**FYM**	**2C:1U**	**1C:2U**	**2FYM:1U**	**1FYM:2U**	CV %	Se± Sig
2003	**4.62.**	**1.85**	**1.72**	**2.66**	**4.1**	**2.30**	**3.68**	**28.0**	**0.99 *****
2004	**4.07**	**1.62**	**1.71**	**3.37**	**4.02**	**3.03**	**4.41**	**20.6**	**0.65 ****
2005	**5.46**	**2.28**	**3.00**	**3.76**	**4.52**	**4.43**	**5.23**	**20.8**	**0.85 *****
Mean	4.72	1.92	2.14	3.26	4.21	3.25	4.44		

Grain yield between three years was consistently high in sole urea, urea(2) compost(1), and urea (2) FYM (1). Grain yields for 2005 were higher than other years due to good weather conditions.

3.5 Effect of irrigation frequency and nitrogen sources interaction on maize yield

There were significant interactions (P<0.01, P<0.001, P<0.001) between the effect of irrigation and nitrogen sources on maize grain yield (Tables 3.3-3.5) in 2003, 2004 and 2005.

In 2003, three nitrogens were sourced from rea (2)FYM(1), (1)C:(2)U, and sole urea obtained highest grain yields of 5.46 t ha^{-1}, 5.37 t ha^{-1} and 5.35 t ha^{-1} at an irrigation of 40 mm every three to four days (Table 3.3). While at an irrigation of 40mm and 40% depletion, only sole urea and (1)C: (2)U nitrogen sources obtained high yields, respectively, but not significantly different from above. Sole compost and sole farmyard manure-sourced nitrogen had lowest mean grain yield in all irrigation frequencies with the least under 40 mm every 14 days..

Table 3.3. Effect of irrigation frequency and nitrogen sources on maize yield (t ha^{-1}) at Kasinthula research during winter 2003

Irrigation frequency	NITROGEN SOURCES AND THEIR COMBINATIONS							
	Urea (U)	Compost (C)	FYM	2C:1U	1C:2U	2FYM:1U	1FYM:2U	Mean
40 mm, three to four days	**5.35**	**2.46**	**2.01**	**3.59**	**5.37**	**3.68**	**5.46**	3.88
40 mm, 7 days	**5.66**	**1.56**	**1.83**	**2.01**	**4.15**	**2.75**	**4.68**	3.52
40% depletion	**3.80**	**2.30**	**1.76**	**2.50**	**5.34**	**1.88**	**2.88**	3.57
40 mm, 14 days	**3.66**	**1.13**	**1.3**	**1.50**	**1.70**	**0.90**	**1.70**	2.69
Mean	4.62	1.92	2.14	3.26	4.21	3.25	4.44	
CV (%)	**28.2**							
S.e	**0.335**							
Sign.	**<0.01**							

In 2004, grain yields from nitrogen sourced from sole urea, 1C:2U and U(2)FYM(1) at 40 mm every three to four days and 40% Depletion were high and not statistically different (Table 3.4). There was a general decrease in maize yield as the urea ratio decreased to zero. The depletion irrigation treatment at 40% had highest yields among the frequencies. Sole compost and farmyard manure obtained lowest yields in all irrigation treatments with the least under 40 mm every 14 days.

Table 3.4: Effect of irrigation frequency and nitrogen sources on maize yield (t ha^{-1}) at Kasinthula research during winter 2004.

IRRIGATION FREQUENCY	NITROGEN SOURCES						
	Urea (U)	Compost (C)	FYM	2C:1U	1C:2U	2FYM:1U	1FYM:2U
40 mm, three to four days	**5.0**	**1.4**	**1.7**	**3.3**	**4.9**	**2.6**	**6.5**
40 mm, 7 days	**4.4**	**1.6**	**1.6**	**2.7**	**3.2**	**3.1**	**3.1**
40% depletion	**5.3**	**1.9**	**1.6**	**3.9**	**5.2**	**3.2**	**6.1**
40 mm, 14 days	**3.5**	**1.7**	**1.9**	**3.5**	**3.9**	**3.1**	**4.2**
S.e±	0.6532						
CV%	20.6						
Sign.	P<0.001						

In 2005, 40% depletion frequency, application of 40 mm every seven days and application of 40 mm every three to four days obtained high grain yields at sole urea treatments. These grain yields were not significantly different from those obtained by 1FYM:2U with the same irrigation frequencies (Table 3.5). Sole compost and farmyard manure were the lowest in yields, only for this year it was higher than for previous years.

Table 3.5. Effect of irrigation frequency and nitrogen sources interaction on maize yield at Kasinthula research station in winter 2005.

IRRIGATION FREQUENCY	NITROGEN SOURCES							Mean
	Urea(U)	Compost(C)	FYM	2C:1U	1C:2U	2FYM:1U	1FYM:2U	
40% Depletion	6.06	2.63	3.23	3.67	4.53	4.13	5.10	**4.20**
40mm, 7 days	5.60	2.43	3.10	4.73	4.37	5.20	5.17	**4.37**
40mm, three to four days	5.73	1.97	3.37	3.53	5.10	4.90	6.10	**4.89**
40mm, 14 days	4.53	2.07	2.30	3.10	4.08	3.47	4.53	**3.44**
Mean	**5.47**	**2.28**	**3.00**	**3.76**	**4.52**	**4.43**	**5.23**	
CV (%)	**20.80**							
S.e	**0.85**							
Sign.	**<0.001**							

Grain yield was positively related to the amount of irrigation for most nitrogen sources and their combinations, though the regression intercept were not significantly different (Table 3.6).

Table 3.6 Regression analysis between irrigation and yield (kg h^{-1}) showing Y-axis intercept, slope, and determination coefficient (R^2) in nitrogen sources for winter 2003, 2004, and 2005, experiments.

Year	2003			2004			2005		
Treatment	Y-Axis	Slope	R^2	Y-Axis	Slope	R^2	Y-Axis	Slope	R^2
Urea	2738.1	2.260	0.72	3439.8	1.346	0.41	4046	1.972	0.52
Compost	887.5	1.182	0.52	1963.1	03790	0.48	2377	-0.001	0.02
FYM	1094.7	0.764	0.93	1882.2	-0.220	0.35	2097	0.001	0.76
U1: C 2	743.7	2.008	0.73	3799.8	-0.545	0.17	3099	0.008	0.19
U1:FYM2	-271.3	3.120	0.99	3912.8	0.469	0.04	3693	0.001	0.78
U 2:C 1	1207.8	3.554	0.62	3432.7	-0.524	0.54	2933	0.002	0.77
U2:FYM1	47.49	4.403	0.97	23736.6	1.501	0.12	3879	0.001	0.91

3.5.2 Water-use efficiency

Water-use efficiency (*WUE*), which was then calculated by dividing the maize grain yield (kg ha^{-1}) by amount of irrigation water for that particular treatment in mm, varied significantly between four irrigation and seven nitrogen sources ($P<0.001$). The grain yield responded differently to different irrigation (mm) and nitrogen sources (Table 3.7-3.9). The results showed maximum WUE in mixed treatments of urea(2)compost(1) or urea(2)FYM(1) for maize crop applied with more water (Figure 3.2.4a), and in sole urea treatment for those that received limited water (Table 3.7-3.9).

Table 3.7. Effect *of nitrogen sources and irrigation frequencies on maize water use (*kg mmh$^{-1)}$*, winter 2003.*

IRRIGATION	NITROGEN SOURCES						
	Urea(U)	Compost(C)	FYM	2C:1U	1C:2U	2FYM:1U	1FYM:2U
40mm,3/4days	4.458	2.050	1.675	2.992	4.475	3.067	4.550
40mm, 7 days	5.896	1.625	1.525	1.906	2.094	2.865	4.875
40% depletion	5.278	3.194	2.444	3.472	7.416	2.611	4.000
40 mm,14days	10.167	3.139	1.083	3.611	4.167	4.722	2.500

Maize water-use efficiency in 2003 depended on amount of irrigation water and nitrogen sources, where water increase (from 360 mm to 1200 mm) reduced WUE as explained by the linear model:

Urea: (Equation 3.1)	WUE = -0.0062x + 11.431,	$R^2 = 0.74$
Sole compost	WUE = -0.0017x + 3.8092	$R^2 = 0.65$
FYM	WUE = 0.0007x + 0.8855	$R^2 = 0.94$
2C:1U	WUE = -0.001x + 3.938	$R^2 = 0.28$
1C:2U	WUE = -0.0003x + 5.367	$R^2 = 0.03$
2FYM:1U	WUE=-0.0024x + 2.1042	$R^2 = 0.26$
1FYM:2U	WUE=0.0022x + 1.2959	$R^2 = 0.65$

Table 3.8. Effect of nitrogen sources and irrigation frequencies on maize water use (*kg mmh*$^{-1)}$ winter 2004.

IRRIGATION	NITROGEN SOURCES						
	Urea(U)	Compost ©	FYM	2C:1U	1C:2U	2FYM:1U	1FYM:2U
40 mm, three to four days	4.167	1.167	1.417	2.750	4.083	2.167	5.417
40 mm, 7 days	4.583	1.667	1.667	2.813	3.333	3.229	3.229
40% depletion	7.367	2.638	2.222	5.132	7.200	4.440	8.472
40 mm, 14 days	9.722	4.722	5.278	9.722	10.833	8.611	11.667

In 2003, use of water-balance scheduling at 40% depletion resulted in high water-use efficiency under 1C:2U nitrogen source, and the longest irrigation schedule of 40mm every 14 days had highest of all under sole urea nitrogen. Long irrigation frequency had greatest grain water use efficiency of 11.667, 12.583 kg mm ha^{-1} followed by water-balance scheduling at 40% depletion that had a highest yield of 8.472, 8.417 kg mm ha^{-1} under 1FYM:2U, 1C:2U, and 1FYM:2U, sole urea in 2004 and 2005 respectively. Comparing with actual yield, Water balance scheduling at 40% depletion had a recommendable WUE as compared with long-irrigation frequency whose high yield cannot equate the gross margin of maize enterprise.

Table 3.9. Effect of nitrogen sources and irrigation frequencies on maize water use (*kg mmh$^{-1)}$*, winter 2005.

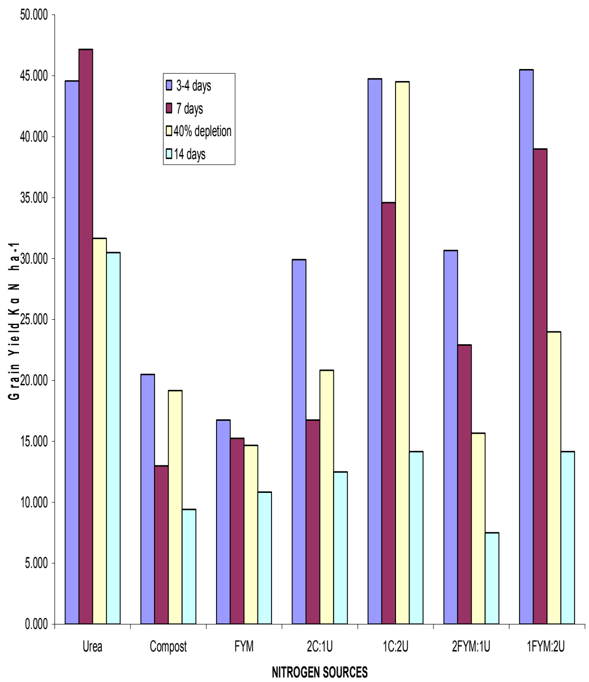
IRRIGATION	NITROGEN SOURCES						
	Urea(U)	Compost	FYM	2C:1U	1C:2U	2FYM:1U	1FYM:2U
40% Depletion	8.417	3.653	4.486	5.097	6.292	5.736	7.083
40mm in 7 days	5.833	2.531	3.229	4.927	4.552	5.417	5.385
40 mm in three to four days	4.775	1.642	2.808	2.942	4.250	4.083	5.083
40 mm in 14 days	12.583	5.750	6.389	8.611	11.333	9.639	12.583

3.5.3 Nitrogen-use efficiency

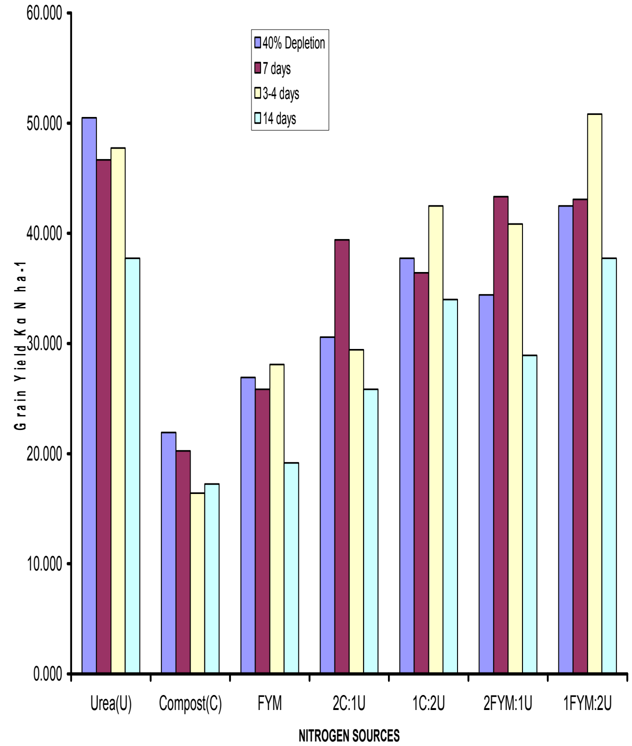
The yield response to nitrogen, which was calculated by dividing the grain yield (kg ha^{-1}) by theamount of nitrogen applied in kg ha^{-1} varied significantly ($P<0.001$) between irrigation and seven nitrogen sources. In 2003, maize that was receiving irrigation every seven days showed the greatest yield response in the sole urea treatments (Figure 3.1, appendix Tables 3.10) with maximum grain yield means of 47.167 kg kgN^{-1}, respectively. This was not significantly different to urea(2)FYM(1), urea(2)compost(1) and sole urea treatments (45.5, 44.75 and 44.583 kg kgN^{-1}) irrigated every three to four days. The minimum grain-yield responses (7.5 kg kg N^{-1}) were observed in FYM (1):(2)urea treatments.

In 2004, irrigation of 40 mm every three to four days showed the greatest nitrogen-use efficiency 54.167 kg kgN^{-1} in the urea(2)FYM(1) nitrogen treatments. This was not significantly different to sole urea, C(1):(2)U and Urea(2)FYM(1), C(1):(2)U, and sole urea under three to four and water-balance scheduling. Use of sole compost and farmyard manure resulted in lowest nitrogen-use efficiency in all irrigation regimes, while the long irrigation regime had lowest nitrogen-use efficiency among the four irrigation regimes with the maximum in sole urea treatment (Figure 3.13).

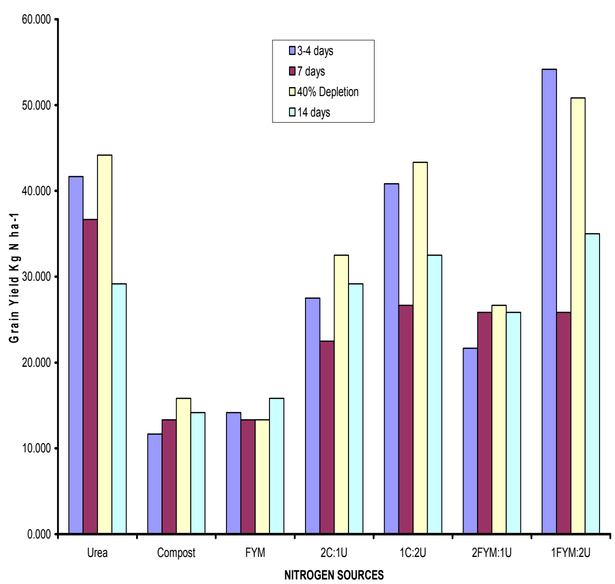
In 2005, water-balance scheduling at 40% had the highest grain yield of 50.5 kg kgN^{-1} under sole urea. This was not significantly different from three to four days irrigation schedule in urea nitrogen treatment.



2003



2004



2005

Figure 3.1. Effect of irrigation frequency and N sources on maize nitrogen-use efficiency (*kg* kgN^{-1}).

Discussion and Final Recommentations

4.1 Irrigation and soil-water content

The initial water application (Figure 2.4) and extraction (Figure 3.2) were uniform across the field. During the subsequent experimental period, soil-water extraction varied with time, depth, and irrigation frequency. Soil-water increased variably between depths of 0-90 cm and uniformy below depths of 90-110 cm in the soil profile between irrigation frequencies. The possible reason for the differences in the upper layer (0-90 cm) was variation in water potential created by different irrigation, while the uniformity in the 90-110 cm depth was due to an equilibrium of the water table that was reached after irrigation, recharging the watertable.

4.2 Crop-water use

The estimated water supply in the 40% depletion and 40 mm in seven days treatments were similar to the maize annual water requirement of 500-800 mm (FAO, 1998). The application of 40 mm every three to four days was (Figure 3.3) above, and that of 14 days irriagion freqeuncy, was below 500-800 mm and estimated *ETc*. Irrigation frequency influenced the amount of crop-water use other than the initial soil-water storage and precipitation, because the precipitation received was not effective for soil-water storage.

4.3 Effect of irrigation frequency on maize yield

The 40 mm, every three to four days irrigation treatment resulted in high grain yield because of adequate water use that reduced yield losses from water stress throughout the season. This increased water and biomass allocation for grain production as compared to 40 mm every 14 days with a water deficit from planting to harvesting. Results for use-of-depletion irrigation at 40% and 40 mm every seven days are not significantly different from 40 mm every three to four days irrigation treatment grain yield. This means that water stress that emanated when using all irrigation regimes was equal (Table 3.1). This shows those irrigation regimes (depletion irrigation at 40% and 40 mm every seven days) are optimal for maize production. The irrigation frequency results showed high maize yield (Figure 3.5) under unlimited irrigation, which agrees with what Hergert et al. (1993) reported, that significant yield can be achieved under optimal irrigation other than under limited or over irrigation.

4.4 Effect of different nitrogen sources and their combinations on irrigated maize yield

The grain yields of sole urea double the overall maize yield of the sole compost and sole FYM treatments. This shows that organic manure had a low short-term contribution to the yield as compared to urea. Yields for urea(2)compost(1) or urea(2)FYM(1) and sole urea treatments (Table 3.2) exceeded the average yields of unfertilized maize for most local small-holder farmers in Malawi. The ranges between 0.7 to 1.1 t ha^{-1} (Douglas, 1994) are within the yields obtained in the urear(1)compost(2), urea(1) FYM(2), sole compost, and sole FYM treatments. This means use of treatment with high urea ratio or sole urea is one way that can effectively increase yield by more than 100% in small-holder farmers, respectively. The use of sole compost or sole FYM and those with less urea ratio cannot bring greater yield increase. Use of combined sources has high economic and sustainable advantages, comperative to the use of sole urea.

A urea combination with organic manure could have directly improved uptake of organic manure in maize by enhancing the organic decomposition or mineralization, or directly improving early maize root development. When the organic manure was improving soil conditions, this might have helped to alleviate soil-water holding and other N limiting factors to maize that each source on its own could not accomplish. Organic manure is advantageous (Lal, 1997) despite its low N contribution, for it improves soil physical, biological, and chemical characteristics that consequently lead to better crop growth in the long term, such as in Malawi and Sub-Saharan countries (Bationo et al., 1998) that use a small quantity of fertilizer and can benefit from the use of combined source of N.

4.5 Effect of irrigation frequency and nitrogen sources interaction on maize yield.

4.5.1 Grain yield and components of yield

Grain-yield response to nitrogen sources was affected by irrigation frequency and ratio of urea to organic manures in the mixture. The longer interval between irrigation resulted in the lowest grain yield (Table 3.3-3.5) in sole compost, with the highest yield being observed in sole urea, urea(2)FYM(1) and urea(2):compost(1) treatment interactions (Table 3.3-3.5). Urea is easily dissolved and easily translocated, compared to sole compost and FYM treatments which are bulky and slow in dissolving. Although organic manure can increase water-holding capacity, it might need more water for easier nutrient dissolving and plant absorption than in inorganic manure in the short term. This shows soil-water dynamics and direct interactions between organic manure and N temporary immobilization that facilitate nitrogen water-use efficiency where mismanagement of the other will affect grain response to N in one way or another.

The average grain yields obtained in urea(2)compost(1), urea(2)FYM(1) and sole urea treatments under irrigation regimes of 40 mm in three to four days, 40% depletion, and 40 mm in seven days are above the actual maize yield estimates for Malawian smallholder winter maize, estate and small-holder summer maize production of 1.86, 1.85, and 1.21 t ha^{-1}, respectively reported by FAO (Josserand and Lewis, 2003) on 2002/2003 maize estimates in Malawi and that of 4 t ha^{-1} set as a standard by FAO. This means that an adoption to the current research findings can improve maize productivity by almost 50% for small-holder winter maize in Malawi.

4.5.2 Water-use efficiency

Irrigation effectively increased maize grain yield (Table 3.7-3.8**),** although water-use efficiency (WUE) expressed as maize grain yield to total water use ratio decreased as irrigation increased, which was also reported by Stone et al. (1987, 1993) and Hergert et al. (1993). Use of different nitrogen sources also had significant effects on water-use efficiency as shown by the high WUE in sole urea treatment for long irrigation frequency and in urea(2)compost(1) or urea(2)FYM(1) treatments for short irrigation frequencies. This reveals that water-use efficiency response to N sources was highly influenced by the urea and organic manure combination (Gustave et al. 2003) and water adequacy as reported by Mahdi (2003) that WUE is high on N-deficient soils where water is applied adequately.

4.5.3 Nitrogen-use efficiency

The NUE for (Figure 3.1, Appendix Tables 3.10-3.12) urea(2)compost(1) and urea(2)FYM(1), respectively, are far higher than the NUE of 14 kg kgN^{-1} reported on Malawi small-holder farmers (FAO, 2000b, Malawi Government 1957-1985), which proves high chances of benefits from the urea-organic combination findings. These findings agree with Ma et al. (1999) who found that there is greater plant N uptake in mixed-N treatment than in sole fertilizer treatment due to the direct contribution of mineral N from the organic manure N and inorganic N. And that nitrogen-use efficiency is greatest when manure rate is small

(Murwira and Kirchmann, 1993) and when there are differences in timing of mineral N from fertilizer and manure. From these related findings, it's quite correct to say that in Malawi, mineral fertilizers alone cannot sustain yields in the long run unless combined with organic manure as reported by Breman and de Wit (1983) and Juo and Kang (1989) for the Sub-Saharan region.

The results also revealed that nitrogen-use efficiency in mixed-N treatment is more water dependent and this correlates with Zougmore et al**. (**2003), who reported that frequent irrigation maximizes fertilize-use efficiency (Russelle et al., 1981). It is quite recommendable to encourage the use of optimum combinations of organic resources and urea under a short irrigation regime to improve the nitrogen-use efficiency in Malawi with the current increase of drought and soil-fertility depletion. The grain nitrogen-use efficiencies for urea(2)compost(1) or urea(2)FYM(1) treatments are greater or equal to sole urea treatment using water balance, seven-day and three to four days irrigation schedules that justify the combination of organic and inorganic N as the most economic and environmentally sustainable fertilization strategy (Paul and Beauchamp, 1993).

The maize yield was above the minimum average maize yield of 4 t ha^{-1} set by FAO; therefore, its findings are of significant importance for maize production improvement. It is appropriate to recommend that the irrigation frequency of 40 mm every seven days and water-balance schedule combined with nitrogen sourced from urea and compost or farmyard manure mixture in the 2:1 ratio is better for systems of maize production with an aim at yield maximization, farmer's affordability, and environmental sustainability in irrigated agriculture. Use of three to four days irrigation uses more water and it's not recommended in motorized pumping irrigation for optimal gross margin. It is also recommended to conduct an economic evaluation on the use of mixed fertilizer as compared to use of sole fertilizer in irrigated maize.

Conclusion

The specific objective for this research was to determine the effect of irrigation frequency and nitrogen source on soil-moisture content in irrigated maize; to determine the effect of compost, farmyard manure, and inorganic fertilizer application on maize performance, maize water-use efficiency, and maize yield response to nitrogen; and to determine the optimum amount of organic manure and inorganic fertilizer combination for irrigated maize in Malawi.

The water-balance schedule, of 40mm every seven days and 40 mm every three to four days accompanied by a combination of organic nitrogen sources, promoted good maize performance, optimal water-use efficiency, and nitrogen-use efficiency that resulted into high grain yield. Long irrigation frequency reduced maize yield in all nitrogen sources and for a consolation yield use of sole urea may give a small but higher grain yield than use of organic manure. High ratio of organic matter in N sources increased water dependency, while high urea ratio decreased water dependency. Use of combined organic and inorganic fertilizers in irrigated maize formed integral soil-water and nutrient management that can optimize efficient use of the limited water and soil resources to achieve sustainable agriculture production in the degraded soils and drought-affected areas of Malawi.

It can be concluded that a water-balance schedule at 40% and 40 mm every seven days in frequency be recommended for winter maize crop in areas with similar climatic conditions as Chikwawa. And that that in times of water shortage, urea can be more easily utilized than organic nitrogen sources.

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FOREST INCOMES AND THE RURAL POOR

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Abstract
Environmental income is defined as rent (or value added) captured through consumption, barter, or sale of natural capital within the first link in a market chain, starting from the point at which the natural capital is extracted or appropriated. The present study, which focuses on forest environmental income had two main objectives. The first was to investigate the extent to which people in rural areas of developing countries depend on income from forest environmental resources, and how this dependence is conditioned by different by different political, economic, ecological, and socio-cultural factors. This is accomplished by a meta-analysis of case studies. The second objective was to review research methodology and make recommendations fort "best practices" in assessment of forest environment income. Although there are substantial variations in methodology and quality of case studies, results indicate that forest environmental income represents a significant income source with an average contribution to household income of some 22 percent in the populations sampled. The main sources of forest environmental incomes are fuel wood, wild foods, and fodder for animals. Forest environmental income has a strong and significant equalizing effect on local income distribution. Cash income constitutes about half of total forest environmental income.

Keys words: forest, incomes, rural poor, sustainable development

Introduction

It is well known that poor people are often directly dependent on natural resources that are not cultivated. But how important, actually, is income from non-cultivated resources? To what extent can we measure it? What are we missing in our poverty assessment? Indeed what is "environmental income?"

Understanding the role that environmental income plays in poor people's livelihoods is important for at least two reasons. First, it helps policymakers design and implement effective poverty-reduction strategies. Second, the size and nature of environmental income has implementations for issues of conservation and sustainable resource use.

There is no generally agreed definition of "environmental income." We settled on the following definition: Environmental income is rent (or value added captured) through consumption, barter, or sale of natural capital within the first link in a market chain, starting from the point at which the natural capital isextracted or appropriated. Obviously, the level of income will be influenced by the degree of processing that might take place before any transaction. For the economically most important categories of forest environmental income (fuelwood, wild food, fodder), however, the modifications of natural capital will be negligible.

The present study, which focuses on forest environmental income, had two main objectives. The first was to investigate the extent to which people in rural areas of developing countries depend on income from forest environmental resources, and how this dependence is conditioned by different political, economic, ecological, and social cultural factors. The second objective was to review research methodology and make recommendations for "best practices" in assessment of forest environmental income.

Forest Environment Income, Income Dependence, Diversification, Distribution, and Poverty

Forest environmental income constituted an average of about 22% of the household income in our sample. Even though agriculture and off-farm income had higher income shares, forest environmental income represented a significant source of income. In absolute terms, the mean annual forest environmental income was about US$ 678 (adjusted for purchasing power party) per household in the sample, while the median income was US$ 346, representing about 19 percent of total income. This indicates a skewed distribution, with some cases of very high forest incomes (US$ 3,460 was the highest). Removing the eight studies with the forest environmental incomes above US$ 1,500, forest environmental income was still around 20 percent of total income, with the average household forest environmental income of US$ 401.

Even if encumbered with substantial uncertainties and variations, the study suggests that forest environmental income contributes significantly to the economic production of goods and services and to welfare levels in these societies. Even contributions that are relatively "small" may be of utmost importance to families living close to the survival line. Omitting such incomes from calculations of national economic statistics and poverty assessments will create biases in the baseline data. If such data are then used in development strategies and programs and in policymaking focusing on livelihoods and poverty, inefficient resource use may occur.

Forest environment income was of particular significance with respect to “gap filling” and safety nets” that are an additional income source in periods of both predictable and unpredictable shortfalls in other livelihood sources.

Wild food and fuel wood were by far the two most important forest products. Fodder was systematically under-reported, but it was important where reported. Cash income constituted about half of total forest environmental income. The share earned in cash declined with higher forest environmental income. We also found a negative relationship between the cash share of forest income and total income. Thus, cash forest products were at least as important for communities with low forest environmental and low total household income as communities that were better off.

Forest environmental income increased with total income, both between the cases (communities) and between households within the communities studied. Forest environmental income was thus important not only for poor communities. The elasticity of forest environmental income with respect to total income was close to unity.

Dependence on forest environmental income, measured as its share of total income, declined with increasing total income when analyzed across households. There was no significant relationship across communities. This tendency was even stronger when looking at the income distribution between households: the poor were more dependent on forest environmental income, which had a strong and significant equalizing effect on local income distribution.

Forest income can be seen as part of rural households’ diversification strategies. We found that high total income was associated with less income diversification, indicating that higher income was achieved through a process of specializing in one or a few high-return activities.

Methodological Problems

The studies reviewed displayed a high degree of theoretical and methodological pluralism, and the substantial variability in reporting of specific variables and results is partly explained through such pluralism. This variability must, however, also be attributed to methodological pitfalls and weaknesses observed in many studies.

Few studies analyzed the role of or even distinguished between different types of forest environmental income, although this usually will be necessary in order to devise appropriate policies aimed specifically at the poor.

Valuation studies reported higher forest environmental incomes than studies focusing on forest environmental income dependence and distribution. This may be due to the inclusion of a wider array of goods in the former type of study, selection of sites with high forest values, or deliberate attempts to inflate the value of conservation. Our data, however, did not permit rigorous investigation of these explanations.

Double counting, even triple counting, was common. Few efforts to define "environmental income" were found, and there was little consistency in measures used across cases. Use of flawed price and cost estimates, such as subsistence good values based on world markets, was prevalent.

Many studies omitted important forest environmental income sources. Unfortunately, some 72% of the studies ignored fodder, causing underestimation of income levels. Fewer than half the studies considered whether current resource use is sustainable.

Recommendations or Research and Best Practices

First, there is a need to "get the basics right" (to avoid the problems just described) in the individual cases studied of environmental income and poverty. Simple research protocols, field methods, and analytical models are needed to understand the role of environmental income in rural livelihoods.

Second, there is a need for more in-depth studies to understand the role of environmental income, both in individual household strategies and in broader development strategies. Is forest environmental income primarily for gas filling and safety nets, an employment of last resort, or a pathway out of poverty? Long-term studies with time series data would help answer these questions.

Further, very few of the environmental income studies deal with issues of local heterogeneity and social differentiation.

Third, there is a need to increase the scope of such studies through larger research projects to get comparable data from different socioeconomic and ecological settings. Our meta-analysis revealed some of the problems of synthesising case studies with widely differing methodologies in objectives. There is a need to generate a larger sample of case studies that have collected a minimum set of comparable data. This will permit a much higher level of generalization. Moreover, analyzing the impact of meso-and-macro-level factors can only be done through a meta-analysis. Achieving this requires a concerted effort by larger players in the research field.

Policy Recommendations

A main policy message to governments' donors and international agencies is that leaving forest environmental income out of national statistics and poverty assessments will lead to underestimation of rural incomes. This will depress average and median incomes and also cause overestimation of the number of rural poor if such estimates are made from household income levels.

In areas where environmental income is important, these problems may be serious and cause substantial rural-urban, inter-sectoral, inter-regional, and international distortions, with flawed conclusions and policies as a result. Furthermore, environments contribute to the livelihoods of the rural poor under changing circumstances.

We also recommend that governments, donors, and international agencies do the following:

- Agree on an operational definition of environmental income that makes income comparable across cases and across livelihood sources.
- Contribute to a worldwide systematic collection of baseline data in the field.
- Include important forest environmental income sources in poverty assessments and in poverty-reduction strategies papers, concentrating on key resources (food, fuel, and fodder).
- Develop sets of policies that secure the resource base; increase possibilities to enhance environmental values of forests; and address issues of dependence, distribution, and diversification among, in particular, poor households and communities.

Conclusions

Forest resources from which environmental incomes are drawn are under tremendous pressure in most of the developing world. Converting forest to agricultural land can be economically sensible and may, in many cases, be seen as a part of a reasonable development process. But with the growing scarcity of forest resources, remaining forestlands increase in value, and the additional land converted to agriculture is typically less productive for agricultural purposes. Conversion processes would nevertheless typically continue, partly because they often entail a transfer of property and partly because many of the benefits from standing forests are local or global public goods in contrast to private agricultural products. The assessments of the economic importance of forest resource use involves individuals with conflicting interests, such as conservationists, timber traders, medicine plant merchants, and agriculturalists. This has strong political implications- a fact well acknowledged by researchers themselves, by bureaucrats, and by politicians. Different stakeholders will find supporters within various parts of the research community. In this context, we believe that transparency, integrated and unified research methods, and increased awareness about the strategic dimensions of research are important.

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ASSESSING IMPLEMENTATION OF THE COMMON AGRICULTURAL POLICY IN FRANCE AND IMPLICATIONS FOR THE FUTURE OF FRENCH AGRICULTURE

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Abstract
Public expenditures to farmers through the Common Agricultural Policy (CAP) of the European Union (EU) represent about 45 % of the EU budget, totaling 49 bn euros in 2005. Since the MacSharry Reforms of 1993, and solidified under Agenda 2000, CAP has increasingly tied more of its expenditures to achieving goals in sustainability. Measures of cross-compliance require farmers to meet animal welfare, land use, and food quality and safety measures in order to receive funds. Advancing rural development and eliminating regional disparities are other central features of Agenda 2000. However, looking at France, the largest beneficiary of CAP funds, the research shows through employing ArcGIS that most CAP funds go to regions with large, highly productive farms instead of small, unproductive farms. Also, small farmers have not made the transition away from price supports to the same degree as large farmers, and thus, likely do not participate in cross-compliance efforts in sustainability as often as large farmers. These circumstances pose a significant dilemma as Eurobarometer opinion polling demonstrates that most French (and Europeans) consider assistance to small farmers and sustainability both integral parts of CAP. Is a tradeoff between supporting the livelihoods of small farmers and promoting sustainable practices necessary? In the aftermath of France's rejection of the May 2005 Referendum on the European Constitution, this is a pivotal moment to consider declared CAP goals in contrast to actual patterns of expenditure and public perceptions about the role of CAP in Europe.

Key words: cross-compliance, direct payments, price intervention, added value, food quality and safety, animal welfare

Introduction

This paper examines implementation of the Common Agricultural Policy (CAP) of the European Union (EU) in France. This is an important consideration, especially in the aftermath of the rejection of the Referendum on the European Constitution, held in France on 29 May 2005. With turnout rates of 69 %, the French voted down the symbolic document by almost a 10-point margin. Although many political commentators noted the strong division by party line, Eurobarometer polling results illustrate a more important demarcation between "oui" and "non" votes. The "yes" vote, driven by a faith in the ideals of the European project, was vastly overwhelmed by the "no" voters who saw large negative economic and social implications of European integration (European Commission, "Post-referendum," June 2005). These results underscore the importance of European policy-making to reflect the interests of national constituencies.

In particular, France is the largest recipient of funds from CAP, which overall totaled 49 bn euros or 45 % of the total EU budget in 2005. EU and French leaders should re-evaluate CAP's effectiveness at achieving its stated goals, in contrast with public perception of CAP's goals and ability to meet these goals. This re-evaluation is necessary if EU and French leaders wish to ensure CAP's ability to deal with agricultural challenges in France and throughout Europe as the EU attempts to integrate 25 members and more. The May referendum illustrated that the EU is accountable and public perceptions matter.

Harmonizing stated objectives of CAP and actual funding practices also matters if the EU is to be a democratic and effective body. In recent decades, CAP's producer-driven priorities and ugly record of environmental and consumer protection has given way to a consumer-centered, environmentally sustainable and family farm friendly set of goals. Beginning with the MacSharry Reforms of 1993 and bolstered by Agenda 2000, CAP's expenditures have shifted from intervention price supports (compensating farmers for the difference between market and CAP stipulated prices) to a growing portion of direct assistance to farmers, based more directly upon their financial needs to protect their livelihoods. Agenda 2000 goals, set in March 1999 at the Berlin European Council meeting, organized CAP policy around a set of goals: "to improve the Union's competitiveness through lower prices; to guarantee the safety and quality of food to consumers; to ensure stable incomes and a fair standard of living for the agricultural community; to make its production methods environmentally friendly and respect animal welfare; to integrate environmental goals into its instruments; to seek to create alternative income and employment opportunities for farmers and their families" (European Commission, "Agenda 2000").

In fact, reorganizing CAP expenditures from guaranteeing prices through intervention spending to direct assistance for farmers represents a vital part of this agenda. The direct assistance is linked to cross-compliance measures to achieve the Agenda 2000 goals in animal welfare, land use, and food quality, thus integrating the Agenda 2000 goals into a single framework. Additionally, Agenda 2000 called for increased cohesion funding, which would provide targeted assistance to underdeveloped rural regions.

However, not only have these idealistic goals not yet been achieved, but the 2005 French Referendum results illustrated that a gap between popular opinion of CAP priorities and actual priorities of CAP expenditures (demonstrated through real-life expenditures) has the potential of halting (or reversing) progress on CAP reform if voters feel that EU policy-makers are out of touch with their constituents. Thus, this paper attempts to expose whether there is a gap between French voters and actual funding priorities for CAP expenditures in France.

Comparing results from analyzing CAP expenditures in France during 2004 and the Eurobarometer survey, "Europeans and the Common Agricultural Policy," yields the conclusion that significant gaps exist between Agenda 2000 stated goals, CAP spending priorities, and French public satisfaction with CAP efforts. In particular, CAP fails to adequately address the needs of less productive agricultural regions. This puts the European project into question, as many French people desire greater assistance to reduce disparity among French farms. Yet, many of Agenda 2000's goals of sustainability have found substantial possibility of being achieved through cross-compliance but only in regions with large, wealthy farms. Intervention pricing has been largely phased out of departments with high productivity and high EU funding, but not in areas of low productivity and low EU funding. Results recommend a shift in paradigm away from CAP responsibility for assisting agriculture in underdeveloped departments towards a broader development scheme through the European Union's Cohesion Policy.

Theory: French Agriculture and Popular Opinion

The historical and theoretical background to this research was primarily informed by (1) A*gricultural Policy and Enlargement of the European Union*, edited by Alison Burrell and Arie Oskam; and (2) Marjoleine Hennis' *Globalization and European Integration: the Changing Role of Farmers in the Common Agricultural Policy*. A third source was Desmond Dinan's *Ever Closer Union: an Introduction to European Integration*.

These works describe the development of French agricultural policy and the effects of CAP on French agriculture. They demonstrate that the gap between large, productive farms and small, unproductive farms in France has been the result of policy of the last half century. As long as CAP has existed, so has its half-hearted attempt to alleviate regional disparities and protect the family farm (Burrell, 2000).

Domestic protection with the goal of modernization has always represented the inherent goals in the "hard core" of CAP market and price policy. Under CAP's watch, total farm holdings in France fell by 41.2% between 1970 and 1995, while simultaneously the average farm size doubled. Modernization in France has led to cheaper food and more stable food supplies, but resulted in an enormous disparity of wealth among farmers. As of 1999, 37& of total farm holdings were smaller than 10 hectares. However, 10% of total farm holdings were larger than 100 hectares, which accounted for 40% of total land use. Hennis writes that the average farm size of 38.5 hectares did not represent the diversity of farm size within France effectively.

Undoubtedly, the French public on the whole has benefited economically from France's ascendance to high agricultural productivity. France is currently the largest net exporting nation of the European Union and second in the world after the United States. As of 1994, French agricultural production represented 21% of total European agricultural production (Hennis, 2005). Yet there are many questions left to answer regarding the public's satisfaction with CAP implementation in France.

From this starting point, the research utilized the European Commission's *Eurobarometer*, "Europeans and the Common Agricultural Policy," to consider areas of CAP in need of reform according to French popular opinion. Conducted in November and December 2004, this poll examines French and European-wide perspectives on CAP. French attitudes towards CAP betray a general support for its contribution to food safety, environmental protection, and direct assistance, while displaying disappointment with CAP's attempts to support small to medium-size farmers.

When asked what the priorities of CAP *should* be, French respondents' second most common answer was to ensure stable and adequate income for farmers (38%). This came after to promote respect of the environment (46%), and before, to ensure that agricultural products are healthy and safe (33%). These top-three priorities are the same as the EU25 average, but in a different order. At the EU average, most respondents were concerned that

CAP ensures stable and adequate income for farmers (36%), and then showed concern over the quality and safety of agricultural products (30%), and protection of the environment (28%).

Respondents were then asked if they believed the current EU agricultural policy to play its role fairly well or fairly badly in respect to what form CAP priorities should take. Of note, only 23% of French respondents believed it to be ensuring stable and adequate incomes for farmers. This quantity was the fourth smallest among the EU25, only above Hungary, Latvia, and Czech Republic, which entered the EU in 2004 and are currently receiving a curtailed portion of CAP funding. The EU25 average was 37%.

Further demonstrating concern for "at-risk" populations dependent on agriculture, French respondents largely noted the failure of CAP in reducing development gaps between regions. Only 26% of French respondents agreed that it was reducing gaps fairly well. Only the Czech Republic and Latvia had smaller portions of the population. As on the previous question, the EU25 average was 37 %.

French respondents disagreed with the notion that European agricultural policy has sufficiently protected small and medium-size farms. Only15% of French respondents agreed that it had done fairly well in this respect. This represents a nine-point decrease from the previous year. Only Finland had fewer (11%) satisfied respondents. EU25 average was 30%.

On the final question to the poll, Europeans were asked what they thought of contemporary developments in CAP: "The EU is subsidizing agricultural products less and less. However, it is granting more funds for the protection and development of the overall rural economy and for direct support to farmers. Do you think that this development is…?" Sixty-six % of EU25 respondents answered that this was a good thing. France supported this proposal beyond the average, with 68%, representing a nine-point increase on the previous year.

Burrell, Hennis, and Dinan describe Europe's agricultural policy in much different terms, standing in strong contrast to the rosy picture of CAP's future posed by the last question of the Eurobarometer. As the relatively undeveloped 2004 Enlargement countries in Eastern and Central Europe begin to receive a larger portion of CAP expenditure through the

2007 to 2014 Financial Perspective, France's funds will likely be cut (Dinan, 2005). The ideal of contributing greater funds towards rural development and direct support for farmers will necessarily come down to the basis of priorities. While a large portion of the French population desires for CAP to do more for poor farmers, the Eurobarometer results illustrate that sustainable practices in land use, food safety, and animal welfare are also high priorities for the public. European agricultural policy must locate a stable balance and effective strategy to meet both sets of objectives.

Methodology

Research Procedure

This research examines agricultural trends across France's 95 departments of mainland France and Corsica. All data comes from the French Agricultural Ministry for 2004. Indicators employed to evaluate French agricultural policy are farm size; productivity of primary agricultural activity (hereafter "productivity"); added value to primary agricultural activity ("added value"); total EU expenditure on agriculture ("EU total expenditure"); proportion of total agricultural expenditure from EU ("EU proportion of total expenditure"); and proportion of total agricultural expenditure on intervention ("intervention spending").

Most of these indicators require little explanation. Productivity covers the value of only the direct farm output, while added value includes a litany of additions to the primary agricultural output. Added value is composed of agricultural inputs including seeds, drugs, and machinery, as well as manufacturing and services that contribute to the processing, wholesaling and distribution, and retailing. Much of added value therefore involves, the "agro-industry" sector, which contributes added value by employing these procedures (Burrell, 2000). Intervention spending goes directly to farmers to compensate them for the difference between the market price and a fixed price that they are promised.

This type of spending is inefficient and is gradually being phased out since the MacSherry reforms in favor of direct payments based upon farmer needs. Total EU spending on agriculture includes direct payments, intervention spending, and any other types of expenditure.

Some of the indicators were created from the original data that I collected, while others are presented in the manner distributed by the French government; for instance, assessing the EU portion of total expenditure on agriculture involved dividing EU expenditure by the sum of EU, national, and local expenditures, each of which were offered by the Agricultural Ministry. Additionally, farm size was computed by dividing the size of the land covered by agriculture in a department by the number of farms in the department.

For the various indicators, all data is presented through ArcMap software on a three-class, quintile classification. This divides the departmental data into three echelons, high, medium, and low, each with roughly an equal portion (31 or 32) of the 95 departments. Chart 1 summarizes the units and values for the indicators. Medium values are not directly considered in the research. Instead, efforts are focused on comparing extreme departments.

Preliminary research, displayed in Chart 2 and Figures 1 and 2, illustrates departmental data regarding relationships among productivity, farm size, and added value. Understanding these circumstances is essential before exploring the destination of EU funds in connection with French agricultural trends in Figures 3-7.

Preliminary Research Questions

1) Is there substantial variety in productivity among French farms? What is the spatial organization of the variation in productivity? What is the level of randomness of the variation? (Chart 2)
2) What is the relationship between farm size and farm productivity? (Figure 1)
3) What is the relationship between productivity of primary agricultural activity and added value to the primary agricultural activity? (Figure 2)

Primary Research Questions

1) What is the relationship between total EU expenditure on agriculture and the productivity of primary agricultural activity? (Figure 3) This relationship was later used as a background for further inquiry ("the expenditure-productivity joint indicator").
2) What is the relationship between the proportions of agricultural expenditure from the EU compared with the expenditure-productivity joint indicator? (Figure 4)
3) What is the relationship of the amount of added value to primary agricultural activity compared with the total EU expenditure on agriculture? (Figure 5)

4) What is the relationship between the levels of added value to primary agricultural activity compared with expenditure-productivity joint indicator? (Figure 6)
5) What is the relationship between the proportions of total agricultural expenditure on intervention compared with the expenditure-productivity joint indicator? (Figure 7)

Results

Preliminary Research Findings

1) **French departments are characterized by a wide range of productivity and a strong tendency for clustering among departments of high and low productivity.** Chart 2 illustrates results of the Anselin Local Morans' I test, which indicates a high level of clustering, especially within two distinct areas of France. The "G-Statistic" hot-spot analysis clarifies that these two groups are differentiated by a cluster of high productivity in the north and low productivity in the south.

   Applying the Morans' I test to all of the other indicators, showed a similarly high measurement of clustering. All indicators, including productivity, registered a "five" rating on ArcMap's one-to-five scale of clustering and represented a less than 1% chance of being randomly distributed.
2) **Farm size and productivity are positively correlated**. Figure 1 illustrates that 15 French departments have high productivity and high farm size, and 16 departments have low productivity and low farm size. In comparison, only six departments have high productivity with low farm size, and only six have low productivity and high farm size.
3) **Farm productivity and added value are strongly positively correlated**. Figure 2 illustrates that two-thirds of all high-productivity departments also have high added value. This trend holds true for low-productivity departments, too: two-thirds of all departments in the low-productivity group have low added value. In strong contrast, only two departments exist in each of the high-productivity-low-added value and low-productivity-high-added-value categories.

Primary Research Findings

1) **Total EU agricultural expenditure and productivity are strongly positively correlated**. In Figure 3, we find that 18 departments with high total EU expenditure

also enjoy high productivity. Sixteen departments have little total EU expenditure and low productivity. Five departments have high EU total expenditure, combined with low productivity, while six have low total EU expenditure but high productivity. This telling relationship serves as the backdrop to further investigations to introduce a third variable. This spatial relationship takes the name, “expenditure-productivity joint indicator” in later figures.

2) **EU proportion of total expenditure is positively correlated to the expenditure-productivity joint indicator**. Moving to Figure 4, 15 out of 18 departments that received high total amounts of total EU expenditure and were characterized by high productivity, also had a high rate of their total agricultural expenditures coming from the EU. On the other hand, 11 out of 16 departments that received a small quantity of EU expenditure and were relatively unproductive also had a small proportion of their public agricultural funding coming from the EU.
   As for departments with low EU expenditure and high productivity or vice versa, it is harder to draw conclusions since there are a fewer number of these areas and they are more equally split by rates of EU expenditure.
3) **Added value and total EU expenditure are related positively, as well.** Figure 5 marks a strong contrast between departments that receive a low total of EU funding and departments that accept a large total of EU funding. A large majority of departments with high total EU funds also have high added value. Almost all departments with low total EU funds have low added value.
4) **Added value varies positively with the expenditure-productivity joint indicator**. Employing the earlier total EU expenditure-productivity backdrop, we see in Figure 6 that as we’d assume, added value follows the trend of Figure 4. However, added value seems to follow agricultural productivity more strongly than the proportion of funds coming from the EU. Fourteen out of 18 departments with high total EU expenditure and high productivity also have high added value, and none of the 18 have low added value. On the other hand, zero departments with low EU total expenditure and low agricultural productivity have high added value, whereas 15 out of 16 have low added value.

Continuing this trend, three of six departments with low EU expenditure and high productivity have high added value. The two departments with low added value and low total EU expenditure, but high productivity, are located just beyond Paris and have high added-value areas nearby. The two departments on the south-eastern coast with low EU total expenditure and high productivity, also have high added value. These departments have adjacent departments with low EU expenditure, low productivity, and low added value. Thus, productivity seems to be a more important driver than EU expenditure in determining whether there will be high added value in a region. Nonetheless, Figure 5 illustrates that EU expenditure is still closely linked to added value.

5) Finally, Figure 7 yields three conclusions. **First, there exists a negative correlation between the rate of spending on intervention and the expenditure-productivity joint indicator when looking at the large number of departments with high-high or low-low characteristics.** This is demonstrated by the large proportion of low-intervention spending in high total EU expenditure-high-productivity departments, compared with the large proportion of high-intervention spending in low total EU expenditure-low productivity departments. However, the proportions aren't as large as in the previous trials, signifying a weaker correlation than in earlier analyses. Figure 7 also illustrates a second finding that within the smaller group of departments (five) with high EU expenditure and low productivity, the proportion spending on intervention is strongly negatively correlated with agricultural productivity. Thirdly, within the small group of departments (six) with low EU expenditure and high productivity, the proportion of spending on intervention is positively related to total EU expenditure.

Discussion

Preliminary research findings describe important characteristics of French agriculture that correspond to the preliminary research questions: (1) A wide variation in average departmental productivity that ranges from 7400 to 65,690 euros per active hectare; a strong north-south distinction between high-productivity and low-productivity zones; and a high level of clustering, representing a small probability of randomness; (2) A strong presence of two types of farms: large, high-productivity farms and small, low-productivity farms; and (3) another distinction: high productivity, high value-added farms and low productivity, low value-added farms.

These characteristics form the setting behind which the EU and French government implements the Common Agricultural Policy within France. Primary research findings illustrate several trends in CAP expenditure allocations in France: (1) in terms of absolute quantities of money, EU expenditure is focused on departments of high productivity with low expenditure in departments of low productivity; (2) another strong distinction exists between departments that receive a high proportion of their funds from the EU (in comparison to local or national sources) and a low proportion of their funds from the EU: the high proportion departments are regions of high productivity and high absolute EU spending, while the low proportion departments are regions of low productivity and low absolute EU spending. This means that local and national authorities perhaps are compensating for the low EU spending, perhaps bringing these regions up to funding levels that rival the highly productive regions. Although this likelihood is important for French farmers, this possibility is irrelevant for our purposes, as we are only concerned with the link between the stated goals of CAP and the actual expenditures of CAP resources.

A further important characteristic of French agriculture is that departments of high total EU expenditure usually have high added value, while departments of low total EU expenditure most likely have low added value. (4) This circumstance is further linked to productivity and demonstrates that departments that have farms which employ intensive practices to their agriculture and other value-added techniques, receive a large amount of EU compensation and also achieve high productivity; (5) another important circumstance is that departments with high total EU expenditure and high productivity receive a lower portion of their funds through intervention, while low total EU expenditure and low productivity tend to result in a high portion of funding through intervention. In addition, departments with low productivity tend to receive a higher portion of their EU funds through intervention spending, whether or not they receive a high or low amount of total EU expenditure.

Through exploring these maps, we have attempted to note general relationships rather than make sophisticated calculations. We have searched for characteristics of French agriculture at the departmental level, which serve as proxies for the larger calculations that could be made with detailed data at a sub-departmental level. In addition, future research could employ more specific variables. For instance, we know that cross-compliance measures are generally linked to direct assistance; however, we did not have data that explains the specific achievements in cross-compliance by French farmers to receive direct assistance funds. In addition, the environmental and human health friendly practices that CAP specifies as objectives in Agenda 2000 may not be stringent enough to be considered "sustainable" according to other experts' standards. Dissecting these variables represents another area of possible research.

Conclusion

Research has shown that within France's agriculture sector marked by a strong contrast between large, productive farms and small, unproductive farms, departments on the large side receive a preponderance of the funding from the EU. Departments with small, unproductive farms receive much less funding. In terms of meeting CAP's Agenda 2000 goals, the objective of guaranteeing a sufficient livelihood for small family farms has much room for improvement. This reality legitimizes concerns of the French citizenry that CAP is underachieving in this area.

At the same time, the low level of intervention pricing in departments of highly productive farms suggests that direct assistance has been effectively introduced in these regions. This is good news for the advocates of the Agenda 2000 goals of sustainability in animal welfare, environmental protection, and food safety, since these standards can be linked to direct assistance through cross-compliance. Simultaneously, small, unproductive farms continue to use intervention pricing to a larger degree, signaling that they either have not been forced to adapt the cross-compliance scheme and may or may not already meet sustainable practices, or that they do not have the ability to meet cross-compliance standards and have therefore, continued to receive funds through intervention pricing. This is an area that requires further research. In any case, shifting away from intervention pricing for farms of all sizes throughout the EU has been an effective method of CAP to improve market efficiency, maintain lower prices for customers, and cut trade barriers with non-EU countries.

Cross-compliance also offers an attractive method of allotting standardized funding based on performance.

These motives explain why it would be wise for European policy makers to assist small farms in shifting away from intervention pricing. If this shift is not undertaken, small farmers will face further difficulties in adapting to the modern economy. In addition, small farmers face the potential of not being able to manage policy-makers' and consumers' demands of sustainability, putting themselves at risk of not complying with Agenda 2000 goals. In the long run, small farmers' failure to comply may be perceived by the larger community as evidence that they are undeserving to receive CAP funds. This would surely be a regrettable outcome of CAP's current high-minded but unsuccessful policy.

Efforts to achieve the Agenda 2000 goals should be bolstered for another and more wide-ranging reason. CAP's perceived failures have the potential to harm the policy-making ability of the European Union in other sectors as illustrated by the May 2005 Referendum results in France when voters refused to grant the EU greater authority due to the perception that the EU was incapable of implementing appropriate social and economic policy. As French (and European) citizens recognize the missed targets of CAP, they will likely (and justifiably) seek policy solutions on the national level and grant the EU less authority.

Fortunately, the relaunching of the Lisbon Strategy places rural development at the core the EU's modernization project. Adopted by the European Council in Lisbon in March 2000, the Lisbon Strategy aims to make "the EU the world's most dynamic and competitive economy" by 2010. The EU Commission's mid-term review or "re-launch" in 2005 re-emphasizes the centrality of cohesion funding to provide employment and growth in rural areas (European Commission. "Rural Development policy 2007-2013"). It is significant that results of this research justify these recent calls by the commission for rural policy reform.

A comprehension review of the CAP policy may suggest that the proper remedy for assisting small, unproductive farmers may be to shift funding from CAP to cohesion funding, which is specifically marked for underdeveloped regions. Such underdeveloped rural regions deserve a broader development strategy than CAP can currently offer. Development of rural land towards recreational use, and preservation of wildlife, forestry, and other diverse practices has numerous benefits. Supporting family farms can also be achieved through targeted more effectively cohesion funding. Unfortunately, France currently receives a pithy portion of cohesion funds, relying mostly on CAP expenditures. The potential for introducing alternatives to agriculture and treating small farms as valuable shareholders, along with their much larger neighbors, becomes a limited possibility since decision making for CAP takes place at the centralized location of the Council of Ministers. Cohesion policy, formulated around the guiding principles of subsidiary (policy at the most local level possible) already allows much greater decentralized decision making.

Transferring a portion of CAP aid to cohesion policy would disassociate rural development policy from the European Union and put more responsibility on local bureaucrats who can have a higher degree of expertise and effectiveness in local affairs. Without these efforts, CAP will likely face further criticism from the French and others who rightly seek adequate rural assistance, as well as sustainable environmental and food quality goals. This research demonstrates that the Agenda 2000 goals are incoherent and inconsistently pursued under current CAP policy. The public's recognition of CAP's failures will ultimately challenge the legitimacy of agricultural policy at the European level and may also endanger other policy areas of the European Union.

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RISK ASSESSMENT FOR URBAN AGRICULTURE

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Abstract

Urban agriculture (actually horticulture) presents special challenges. In conventional agriculture the main risks to be considered are related to use of pesticides, fungicides, and herbicides on the crop of interest, or other crops within the rotation. Few areas have widespread contaminants, although arsenic in irrigation water or a high natural background of certain other elements may occasionally present concerns. Urban sites, however, present many opportunities for anthropogenic contaminants. Heavy metals, particularly lead, may be present at high concentrations in dust that falls on the crop. Persistent organic pollutants such as PCBs or PAHs, and chlorinated low-volatility pesticides including chlordane and DDT may be present in the soil and in dust. In cities where there is a tradition of allotment gardens or backyard gardens, risks may be lower than when former industrial and residential sites are converted to small-scale intensive cropping. Little information is available on how typical urban dwellers of previous generations treated insect and weed infestations, but currently, individual homeowners are known to apply rather heavy doses of control agents and fertilizers. Thus there may be residual risks, particularly with materials that have a long half-life, such as chlordane or arsenate of lead. We attempt to provide risk-assessment tools and apply them to some specific cases of urban agriculture. Different crops, consumption patterns, and settings are examined. The presentation includes a review of the literature on risk assessment for urban agriculture.

Key words: urban agriculture, food crops, contaminated soil, lead, pesticides, risk assessment

Introduction

The term "urban agriculture" appears to be a relatively recent introduction, although agriculture and horticulture have been happening in the proximity to urban centers throughout recorded history. For purposes of this paper, all vegetable, fruit, and grain production, independent of scale, is considered. The key factor is that it is agriculture or horticulture in densely populated areas or near industry. One half of the world's population is or soon will be urban. Agriculture will continue and although the large majority of grain production will occur distant from large urban centers, there will be a significant fraction of fruits and vegetables produced relatively close to their ultimate market, particularly in countries with high population density.

Sources of Risk

We may readily identify several sources of risk in urban agriculture. These include lack of regulations on waste/pollution; brownfields reclamation and conversion to production; low relative value of agriculture which drives to lands of lesser value; marginalization of agriculturalists who may be less well educated and have lower status in a society; and informal, unintended use of contaminated land where the identity and hazards of contaminants is often unknown to those cultivating the land. These different risk sources vary in importance from one urban area to another. There is poor documentation of risks, or even contamination levels, for persistent organic pollutants that may occur sporadically. There is better, although incomplete, information for heavy metals including lead, cadmium, arsenic, and copper.

Populations at Risk

The magnitude of populations at risk are largely a function of the scale of production in urban areas. For the U.S., a much smaller fraction of total vegetable and fruit production occurs in dense urban areas than is true of most other countries. A best estimate from surveys is that one-fourth of the U.S., households have a vegetable garden (B. Butterfield, National Gardening Association, personal communication, June 2006). There are about a half million using community gardens in U.S. according to the community garden association. Allotments are traditional in Europe and serve a larger fraction of the population in at least some countries. Up to 40% of vegetables in some areas, such as Poland or the former Soviet Union, are grown in urban conditions. Agriculture continues in rapidly developing urban areas worldwide until forced out by population growth. Thus at the fringes of growing urban areas there is considerable production in close proximity to industry.

Relative Risk

Contaminants of concern in urban settings include heavy metals-lead, cadmium, copper, nickel, and zinc; semi-metal arsenic; and persistent organic pollutants, in particular polychlorinated biphenyls, DDT, chlordane, and dioxins. Lead may be the number one risk in already industrialized cities with high numbers of automobiles because lead is a potent neurotoxin at low levels in children; high soil levels follow leaded gasoline use and leaded gasoline was used in many cities into the 21st century; secondary smelters and reprocessing of (particularly automotive) batteries occurs on urban fringes, often with poor regulatory oversight; and lead paint was widely used in older urban areas and has persisted on and in houses for many decades.

Magnitude of the Lead Source Problem

Typical lead levels in central city soils' upper layers show a total to 1000 mg/kg, median ~500 mg/kg. Available lead levels are commonly up to 500 mg/kg, median ~200 mg/kg. A representative sample of lead levels follows.

Table 1. Lead in urban soils.

City region	Garden type	mg/kg soil* median, mean, 90%	Year, ref.
Boston, MA	900 garden samples	>500, 800, 1500	1979, Spittler & Feder
Baltimore MD, 30 mi radius (48 km)	yard soils, 0-20 cm, n=422	100, N/A, 777	1983, Mielke et al
New Orleans LA, all census tracts	census tract soils, 0-2.5 cm (n>10 each)	200, N/A, 700	1997, Mielke et al
St. Paul, MN	yard soils, 0-2 cm	150, N/A, 600	1988, Mielke et al
9 U.K. cities	94 gardens, 0-15 cm	217 geo mean all, [125-526 by city]	1990, Moir & Thornton
London boroughs	574 gardens, 0-5 cm	654 (geo. mean)	1988, Culbard et al
5 Kazakhstan cities	residential area soils	150-760	1998, Aarhus

* Median and geometric mean are most useful values for comparison. The 90% values indicate the extent of tailing to the high side of the distribution, and serve to indicate the extreme risk situation.

Magnitude of the Lead Contamination of Foods

Lead transfer to food crops and other vegetation occurs by two routes. The first is uptake via roots yielding leaf levels ~ 1% of soil total concentration when calculated on a dry weight basis. In different studies, the ratios range from 0.001 to 0.03 lead availability depending on soil type. Many older studies must be disregarded because there was unavoidable contamination in transport and analysis, or via the second route. The second route is direct contact and sorption. This is highly variable and may give up to ~10% of soil levels calculated on a dry weight basis. This relatively high apparent accumulation is because leafy plants have a large surface area and low relative dry matter and can trap lead sources, including ultrafine particulates from lead emitting sources, or dust and rain-splashed material from the soil surface.

Table 2. Lead content in field crops and domestic vegetables, sampled from agricultural fields and as marketed through the normal U.S. food chain.

	Wolnik et al* 1980s	FDA, Market basket** 2005	FDA, Market basket** 2005
	mg/kg fresh wt	mg/kg fresh wt	mg/kg dry wt
Lettuce	0.013	0.005	0.1
Potato	0.009	0.003	0.018
Corn (sweet)	0.0033	0.001	0.004
Carrots	0.009	0.003	0.024
Onion	0.011	0.002	0.022
Spinach	0.045	0.014	0.17
Tomato	0.002	<0.002	<0.03

*The first three crops are from Wolnik et al., 1983; the next four are Wolnik et al., 1985. These were obtained in production fields during a time when leaded gasoline use was just beginning its decline in the U.S.

** Values are for nearest equivalent to Wolnik et al. (1983, 1985) for a prepared food, or raw leaf lettuce, baby carrots, onion, and tomato. Lead was detected in 2/4 lettuce, 3/41 fresh corn, 10/34 baked potato, 1/4 carrots, 1/43 corn chips, 5/44 onion and, 35/44 boiled spinach. None of these foods exceeded 0.02 mg/kg in any sample, except spinach with one at 0.06. Overall, 2,377 samples out of 11,422 had “trace” and only ~200 had reliably detectable levels of lead in the entire market basket survey. Consistently higher median values were seen in fresh /frozen boiled spinach (35/44) at 0.011 mg/kg, fresh/frozen boiled collards (33/44) at 0.009 mg/kg, and baked sweet potato (30/40) at 0.011 mg/kg. Dry wt. values are estimates using water content values from Bogert et al. (1973).

Diet vs Other Lead Sources

Historically, diet has been a major route of potential lead ingestion for all ages. Food and beverage intake is 1-2 kg/day fresh weight per day (not counting drinking water). For young children, up to 1 kg/day food and beverages may be consumed, with more from fruit juices rather than coffee, tea, or water. Lead may be contained in food or sorbed to it from dust and dirt. Homegrown vegetables may contain 10 to 40 mg/kg dry wt when grown on soil with 1000 mg/kg lead (Finster et al., 2004).

Target for total lead intake in children is for it to be less than 10 ug/day, a very low value (EPA, 2006). Direct soil or house-dust ingestion is major contributor in many locations because, as shown in Table 1, many urban soils contain high levels of lead, and house dust reflects soil dust plus lead paint. Ingestion of only small amounts of dust can result in relatively large inputs (e.g., 20 mg consumed/d @ 500 mg/kg = 10 ug intake). Drinking water contributes on average < 2 ug/day. Air inhalation contributes very little when no leaded gasoline is used. As shown in Table 2 and documented by USEPA (EPA 2006), U.S. commercial foods (other than vegetables) contribute < 3 ug/day. Realistic estimates for consumption of commercial leafy vegetables indicate they make a small contribution. This leaves home-grown vegetables as a major variable source.

A more precise estimation of lead contribution of fresh vegetables may be based on likely consumption levels. A two-year-old consumes ~6 g/day (fresh wt) root or leafy vegetables and up to 12 g/day other vegetables of kinds that are likely to be grown at home. Lead accumulation in root or leaf (fresh wt basis) attains 1/400 to 1/2000 of soil level; we may assume 1/1000 as typical. With a soil lead level of 500 mg/kg, plant material is on average carrying 0.5 ug/g lead or 6 ug/day with 12 g of leafy or root vegetables in the diet. Seasonality restricts most produce items to consumption of 1/10 of the year, so on average taken over the whole year is 0.6 ug/day. Fortunately, this is a small fraction of the total target level of 10 ug/d.

A high-risk scenario would be an accumulation ratio of 1/400, vegetable lead/ soil lead yielding 1.5 ug/day, if the same assumptions about consumption were used. A five times greater consumption of vegetables on soil with 1000 mg/kg lead would give a further ten-fold increase in intake. In this instance, homegrown vegetables could contribute more than the target level of 10 ug/day. This is a fairly low probability scenario for children in the U.S. but may not be unreasonable for low income children in many densely populated, rapidly urbanizing areas.

The EPA IEUBK model provides estimates of blood lead related to inputs. These results are extracted from a study done by the Missouri Department of Health (1995) for potential targets in the Joplin, Mo., area where high soil levels of lead were present and vegetables were grown on those soils. For vegetables, an intake of 17 ug/day may give a 3-4 ug/dL increase in blood lead. Current blood lead levels in U.S. children are near 2 ug/dL, except in central cities. Ingestion of dirt or dust will easily provide 10-20 ug/day and potentially much more. For children eating large amounts of homegrown produce from highly contaminated soils, there is a definite risk of significant elevation of blood lead levels.

However, the predicted elevation, to 5-7 ug/dL, is still below values that were typical of all children in the U.S. two decades ago.

From the limited number of extensive reports provided for children internationally, it appears that blood levels are in decline everywhere that leaded gasoline has been phased out. Decreases are fairly rapid and large. Blood lead levels above 10 ug/dL are becoming increasingly uncommon except when industry continues to release large amounts of lead from lead smelters. Urban homegrown vegetables will continue as a risk factor so long as the lead is available in soil
(Finster et al., 2004).

While lead may be the largest risk factor for urban agriculture, a second risk is cadmium, which may be high in biosolids and industrial wastes. Biosolids may be applied to urban allotments or agricultural areas. This will depend on regulations in each country, both to prevent industrial sources of cadmium release and to control biosolids applications. In the U.K., there is no evidence for cadmium levels elevated in urban vs rural areas. In Berlin, one area of biosolids disposal gave crops with high cadmium. Rice may be an effective cadmium accumulator. In the U.S., there is no evidence for increased cadmium in crops where biosolids are disposed

Persistent organic pollutants, chlorinated hydrocarbons, dioxins, and PCBs are uncertain risk factors often associated with brownfields and industrial contamination. The Arachlor series were widely used in transformer oils and spills have occurred. The extent of contamination is poorly documented. Both DDT and chlordane were widely used as insecticides for decades but have been banned in most temperate climates for a considerable time so that only randomly located high-level patches and a general background elevation may remain. Dioxins generally are present at only low levels from incinerator operations and as by-products from a few industrial processes. The polycyclic aromatic hydrocarbons are more generally widespread and are found wherever asphalt and tar have been used, or from manufactured gas plants that yielded coal tar as a by-product. Although many of these different organic pollutants are known to bioaccumulate and are likely carcinogens, there is little information on how urban agriculture might interact with their presence. For most low-solubility compounds such as chlordane, there is expected to be little uptake by plants, although there are some marked differences between species (Mattina et al., 2000). Urban areas have high levels of a wide range of pollutants and in the instance of New Orleans, there is a strong association of PAHs and lead (Mielke et al., 2001). Levels are >10x above the regional background but several-fold lower than in a nearby bayou. Because the uptake by plants is low, deposition from dust is a common source of contamination, as with lead.

Risk-Reduction strategies

Replacement of soil is often an effective means to reduce lead contamination of crops if the source is soil and not windblown dust. Deposition from exhaust fumes is no longer an issue as lead-containing fuel has been banned in almost all markets. Washing leaves or peeling root produce will lower contamination levels, if the contaminants are not incorporated into the main part of the plant. For lead, a portion of deposited lead cannot be removed by washing, but root-associated lead can be peeled away. Fruits are generally the least contaminated produce as seen in Table 2. Leaf crops are the worst. Avoidance of certain crops, particularly those consumed as leaves, will reduce risks by a large factor. For the persistent organic pollutants, their sorption is often too tight to remove with ordinary washing because they sorb to the waxy coating of leaves.

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EFFECTIVENESS OF ELECTROSTATICALLY CHARGED-WATER SPRAY IN REDUCING DUST CONCENTRATION

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Abstract

The effectiveness of electrostatic-charged-water droplets in reducing dust concentration was investigated in an enclosed experimental chamber (2.4 m x 2.4 m x 3.6 m). Test particles (i.e., corn starch, NaHCO3) were first dispersed into the chamber by using a pressurized canister. Charged-water droplets were then sprayed into the chamber. Ssize distribution, number concentration, and mass concentration of the test particles were monitored with an Aerodynamic Particle Sizer™ spectrometer. From the spectrometer data, particle-removal efficiency for the charged-water spray was determined. Performance of charged-water spray was also compared with that of uncharged-water spray and no water spray. Results showed that the charged-water spray was significantly more effective than either the uncharged-water spray or no water spray. Particle-removal efficiency of the charged-water spray (4-min spray duration, 120 mL/min), based on mass, ranged from 88% to 92% for particles ≤ 10 µm equivalent aerodynamic diameter and from 34% to 70% for particles ≤ 2.5 µm equivalent aerodynamic diameter.

Key words: indoor air quality, dust control, charged-water spray

Introduction

Poor air quality is a growing concern in livestock confinement buildings. A growing body of literature has documented health problems among workers in these operations. Donham (1999), for example, reported the following statistics on swine confinement workers: (1) at least 60% of workers surveyed have acute or subacute respiratory symptoms including dry cough, chest tightness, and wheezing on exposure to the work environment; irritation of the nose, eyes, and throat; and stuffy nose and throat; (2) at least 25% of the workers surveyed have periodic, acute, febrile episodes with fever, headache, muscle aches and pains, chest tightness, and cough; and (3) at least 25% of the workers surveyed experience chronic bronchitis, occupational (nonallergenic) asthma, and noninfectious chronic sinusitis. In addition, previous research (Donham et al., 1989; Donham et al., 1995; Reynolds et al., 1996) has suggested the following exposure limits for swine confinement workers: 2.4 mg/m^3 total dust, 0.23 mg/m^3 respirable dust, and 7 ppm ammonia.

Air quality in livestock buildings should be improved to prevent occupational health problems. Engineering control strategies include (1) reducing emission or generation rates of the air contaminants (i.e., source control); (2) dilution and/or effective room air distribution (i.e., ventilation control); and (3) air cleaning (i.e., removal control). Source control strategies for dust include use of feed additives (fats or oils), cleaning of dusty surfaces, and spraying water or oil over dusty surfaces. Ventilation control includes purge ventilation and effective room-air distribution systems. Air cleaning strategies include use of air filters, ionizers, or wet scrubbers. Dust reductions reported with these strategies have ranged from 15% for weekly washing of pigs and floors, to 23% with ionizers, to 76% with a rapeseed oil spray (CIGR, 1994). Other reports of ionizer efficiency have ranged from 31% (Czarick et al., 1985) to 92% (Mitchell, 1998). Other studies (Carpenter, 1986; Madelin and Wathes, 1988) have shown that reducing airborne dust levels by 50% can reduce airborne bacteria by 100-fold or more.

A potential dust-reduction method is spraying charged-water into the airspace. Hoenig (1977) and Gillespie (1955) have shown that most dust particles acquire electric charges as they are dispersed into the air. Polarity and magnitude of the charges on these particles depend upon their size and origin (Hoenig, 1977; Hassler, 1978). Therefore, particle-collection efficiency of water droplets can be significantly enhanced via electrostatic forces of attraction if the droplets are charged to the opposite polarity (Mathai, 1983). Increasing electrostatic force of the water droplet can dramatically increase collection of particles, even for small particles.

The major objective of this study was to evaluate the potential of electrostatic-charged-water sprays in controlling dust particles in enclosed spaces. Specific objectives were to (1) compare charged-water spray, uncharged-water spray, and no-water spray in terms of dust-removal efficiency; and (2) determine the effects of charged-water spray duration, method (i.e., continuous vs. intermittent), charge polarity, and ambient relative humidity on dust-removal efficiency.

Materials and Methods

Experiments were conducted in an enclosed experimental chamber (2.4 m x 2.4 m x 3.6 m), maintained at normal room temperatures. The chamber was equipped with particle-measuring instruments, including an Aerodynamic Particle Sizer™ (APS) spectrometer (Model 3321, TSI Inc., St. Paul, Minn.) and a Scanning Mobility Particle Sizer™ (SMPS) spectrometer (Model 3936, TSI Inc., St. Paul, Minn.).

Test particles

Two types of test particles were considered: corn starch and sodium bicarbonate ($NaHCO_3$). These particles were selected based on safety, size distribution, and relative net-charge-to-mass ratio. Particle densities, as measured with a multipycnometer (Quantachrome Instruments, Boynton Beach, Fla.) were 1.53 g/cm^3 (standard deviation, SD=0.06 g/cm^3) and 2.22 g/cm^3 (SD=0.02 g/cm^3) for corn starch and $NaHCO_3$, respectively. The test particles also had different relative electrostatic charges. For example, when dispersed into the experimental chamber by using a pressurized canister equipped with an aluminum nozzle, the net-charge-to-mass ratios (as measured with a dynamic Faraday-cage sampler) were -0.11 milliCoulumb/kg, or mC/kg, (SD=0.07 mC/kg) and +0.20 mC/kg (SD=0.001 mC/kg) for corn starch and $NaHCO_3$, respectively.

Measurement of size distribution

Size distribution and number concentration of the airborne particles were monitored by using the APS spectrometer. This spectrometer measures the equivalent aerodynamic diameter (EAD) of particles from 0.54 to 20 μm, and uses an air sampling rate of 1.0 L/min. The spectrometer was connected to a dilution unit, which was set at a 100:1 dilution ratio. Both the dilution unit and the APS were located near the center of the experimental chamber. In some experiments, the SMPS spectrometer was used to measure the concentration of particles from 20 to 835 nm equivalent mobility diameter.

Electrostatic-charged-water spray

The electrostatic-charged-water spray was generated by induction charging. A commercially available electrostatic spraying system (Electrostatic Spraying Systems, Inc., Watkinsville, Ga. 30677 USA) was used to generate the charged-water droplets. The spraying system was operated at a liquid flow rate of 120 mL/min (water tank pressure of 15 psig), and droplet size of 30 to 40 μm.

Experimental design and procedure

Five sets of experiments were conducted. Each of the sets is described below. Most experiments used the negatively charged-water spray with a charging level of approximately -6 mC/L.

1. Comparison of charged-water spray, uncharged-water spray, and no-water spray. The no-water spray treatment served as the control and was used to account for removal of particles by gravitational settling. Both the charged-water spray and uncharged-water spray treatments involved spraying water into the chamber continuously for 4 min. For $NaHCO_3$, the numbers of replicates were 6, 3, and 4 for the charged-water spray, uncharged-water spray, and control, respectively. For corn starch, the corresponding numbers of replicates were 4, 3, and 3.

2. Effect of spray duration on dust-removal efficiency. The charged-water spray system was operated at spray durations of 2, 4, and 6 min. A liquid flow rate of 120 mL/min was used. The equivalent total volumes of water sprayed into the chamber were 240, 480, and 720 mL for the 2-, 4-, and 6-min spray durations, respectively. For $NaHCO_3$, the numbers of replicates were 3, 6, and 3 for the 2-, 4-, and 6-min spray durations, respectively. For corn starch, the corresponding numbers of replicates were 3, 4, and 4.

3. Comparison of continuous and intermittent water spray. The effect of spray method on removal efficiency of charged-water spray was also evaluated. Tests were conducted to compare spraying of charged-water (4 min spray duration) with two methods: continuous and intermittent. The intermittent method involved spraying for 1 min, 4 times, with a 1-min interval between sprays. For $NaHCO_3$, the numbers of replicates were 6 and 3 for continuous and intermittent sprays, respectively. For corn starch, the corresponding numbers of replicates were 4 and 3.

4. Effect of charge polarity. Experiments compared negatively charged with positively charged-water spray using a spray duration of 4 min. The positively charged spray was operated with a charging level of approximately +7 mC/L. For $NaHCO_3$, the numbers of replicates were 5 and 3 for the negatively charged and positively charged-water sprays, respectively. For corn starch, each polarity had 3 replicates.

5. Effect of ambient relative humidity. Experiments compared 40% relative humidity with 80 % relative humidity using negatively charged-water spray with a spray

duration of 4 min. For $NaHCO_3$, the numbers of replicates were 5 and 3 for the negatively charged and positively charged-water sprays, respectively. For corn starch, each level of humidity had 3 replicates.

For each experiment, the experimental chamber was prepared by cleaning the surfaces and running its air filtration system. The ventilation and air filtration systems were not operated during the experiment, so that air exchange in the room was primarily through natural infiltration/exfiltration. The concentration of particles was measured (1 min/sample) with the APS before dispersion of the particles and 2 min after dispersion. The measured concentration 2 min after dispersion was considered the initial concentration.

The particles were dispersed by using a pressurized canister at 80 psig (time t =0). A nominal mass of 20 g was used; the actual mass deployed ranged from 7.4 to 12.5 g for corn starch and from 2.7 to 8.3 g for $NaHCO_3$. Dispersion took approximately 2 sec. To further disperse the particles inside the chamber, two mixing fans inside the chamber were operated for about 2 min after deployment of the particles.

The charged-water droplets were sprayed into the chamber starting at t =3 min (i.e., 3 min after particle deployment) for 2, 4, or 6 min. The concentration of the airborne particles was measured from t =10 min to t = 60 min (1 sample/min). The measured concentration at t =10 min was considered in calculating the removal efficiency.

Data analysis

From the number concentration data from the APS, the corresponding mass concentration for each size range was calculated by using the following equation:

$$C_m = \frac{\pi}{6}\rho_o d_a^3 C_n \qquad (1)$$

where C_m is the mass concentration, C_n is the number concentration, ρ_o is the standard density (1000 kg/m^3), and d_a is the EAD. Removal efficiency for a given size range was determined from the mass concentration, that is,

$$\eta = \frac{C_{m,2} - C_{m,10}}{C_{m,2}} \qquad (2)$$

where η is the removal efficiency based on mass concentration, $C_{m,2}$ is the mass concentration for the particle-size range before spraying (i.e., at t=2 min), and $C_{m,10}$ is the mass concentration for the particle-size range after spraying (i.e., at t=10 min). Removal efficiencies for particles ≤ 10 μm EAD (η_{10}) and for particles ≤ 2.5 μm EAD ($\eta_{2.5}$) were determined based on the mass concentrations of particles ≤ 10 μm EAD and of particles ≤ 2.5 μm EAD, respectively.

The removal efficiencies were analyzed by using PROC GLM of SAS (Version 9.1, SAS Institute, Inc., Cary, N.C.). Treatment means were compared by using Duncan's Multiple Range Test at a level of significance of 5%.

Results and Discussion

Effectiveness of charged-water spray

Figures 1 and 2 show the particle-size distributions, based on mass concentrations, for $NaHCO_3$ and corn starch, respectively, before and after spraying of the charged-water droplets. The charged-water spray reduced the mass concentrations for all sizes. As expected, the reduction increased with increasing particle size. It should be noted that the reduction in dust concentration was due to the combined effects of the charged-water spray and gravitational settling of the test particles.

Table 1 summarizes the geometric mean diameters (GMD) and geometric standard deviations (GSD) of the distributions in Figures 1 and 2, and also the distributions for the no-water spray treatment. For each type of particle, the control and the charged-water spray treatment did not significantly differ ($P>0.05$) in the mean initial GMD (i.e., at t=2 min). At t=10 min, however, the charged-water spray treatment had a significantly lower ($P<0.05$) mean GMD than the control. The lower GMD for the charged-water spray treatment is due to the removal of the large particles by the charged-water droplets. For each treatment, comparison of the initial GMD and the GMD at t=10 min showed a significant reduction

($P<0.05$). The reduction was higher for the charged-water spray treatment, compared with the control, again because of the additional removal of the large particles by the charged-water droplets.

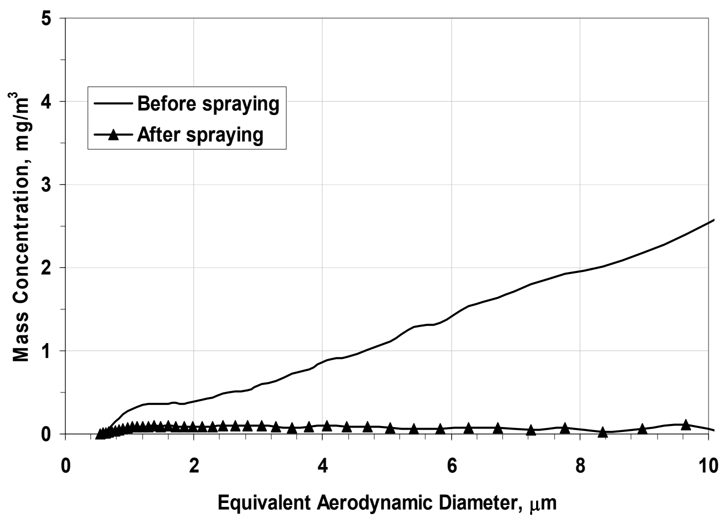

Figure 1. Mass-size distribution of $NaHCO_3$, before and after charged-water spraying, as measured by the Aerodynamic Particle Sizer™ spectrometer. The duration of spraying was 4 min at 120 mL/min.

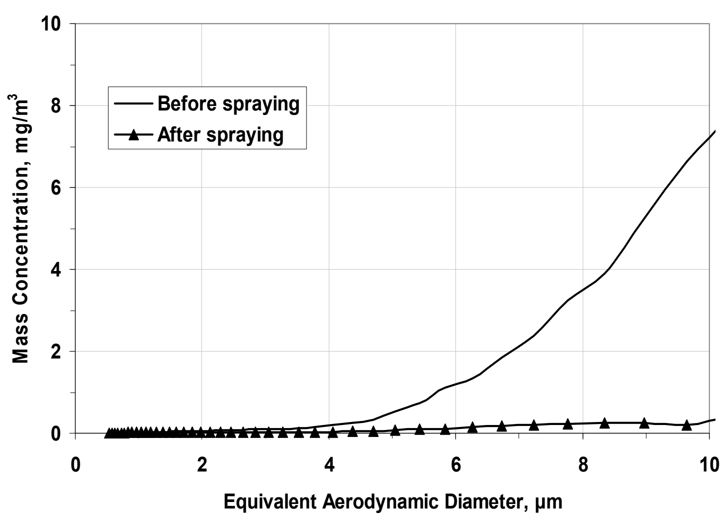

Figure 2. Mass-size distribution of corn starch, before and after charged-water spraying, as measured by the Aerodynamic Particle Sizer™ spectrometer. The duration of spraying was 4 min at 120 mL/min.

Table 1. Geometric mean diameter (GMD), mass basis, and geometric standard deviation (GSD) for the charged-spray treatment (4-min spray duration, 120 mL/min) and control (no water spray).[1]

Treatment	Corn Starch				$NaHCO_3$			
	Initial (t=2 min)		At t=10 min		Initial (t=2 min)		At t=10 min	
	GMD[2] µm	GSD	GMD[2] µm	GSD	GMD[2] µm	GSD	GMD[2] µm	GSD
Charged-water spray	13.1 a	1.37	7.3 a	1.99	6.1 a	2.22	2.4 a	2.11
Control (no-water spray)	13.0 a	1.40	10.0 b	1.59	5.9 a	2.23	4.0 b	2.20

[1]Particle concentrations were measured with the Aerodynamic Particle Sizer™ spectrometer.
[2]Column means with the same letter are not significantly different at 5% level of significance.

Table 2 summarizes the removal efficiencies (η_{10} and $\eta_{2.5}$) for corn starch and $NaHCO_3$. In general, the charged-water spray treatment had significantly ($P<0.05$) higher particle-removal efficiency than either the control (i.e., no-water spray) or the uncharged-water spray treatment. For particles ≤ 10 µm EAD, the charged-water spray resulted in mean removal efficiencies of 88% for $NaHCO_3$ and 92% for corn starch. For particles ≤ 2.5 µm EAD, on the other hand, the charged-water spray resulted in removal efficiencies of 70% for $NaHCO_3$ and 33% for corn starch.

Particles, particularly the large ones, are also removed by gravitational settling. For example, particles with 10 µm EAD have terminal settling velocities of 0.30 cm/s under normal conditions of temperature and pressure. For particles ≤ 10 µm EAD, the control (i.e., no-water spray) had mean removal efficiencies of 37% for $NaHCO_3$ and 53% for corn starch. The lower removal efficiency for $NaHCO_3$ could be due to its lower initial GMD, compared with that of corn starch. As expected, for the control, the removal efficiency for particles ≤ 2.5 µm EAD, which have lower settling velocities than particles ≤ 10 µm, were considerably lower at about 28%.

It was surprising that the uncharged-water spray was not effective, compared with the control, even for the larger particles. Although the η_{10} for corn starch was 62%, it was only 31% for $NaHCO_3$. In addition, the $\eta_{2.5}$ values for the uncharged-water spray treatment were close to zero, indicating that the water droplets were unable to collide with the small dust particles. Evaporating water droplets could also have contributed to the mass of particles ≤2.5 µm EAD, resulting in negligible removal efficiency for the solid particles.

Table 2. Removal efficiencies (mass basis) for corn starch and $NaHCO_3$ of charged-water spray (4-min duration at 120 mL/min), uncharged-water spray (4-min duration at 120 mL/min), and no water spray.[1]

Treatment	Corn Starch				$NaHCO_3$			
	η_{10}		$\eta_{2.5}$		η_{10}		$\eta_{2.5}$	
	Mean[2]	SD	Mean[2]	SD	Mean[2]	SD	Mean[2]	SD
Charged-water spray	0.92 a	0.02	0.33 a	0.08	0.88 a	0.03	0.70 a	0.07
Uncharged-water spray	0.62 b	0.07	0.01 b	0.01	0.31 b	0.06	0.00 b	0.10
Control (no water spray)	0.53 c	0.04	0.28 a	0.07	0.37 b	0.04	0.28 c	0.01

[1]Particle concentrations were measured with the Aerodynamic Particle Sizer™ spectrometer.
[2]Column means with the same letter are not significantly different at 5% level of significance.

Figure 3 summarizes the removal efficiency for the submicrometer particles (measured by the SMPS spectrometer). Compared with the control, the charged-water spray treatment had higher removal efficiency for the 20 to 835-nm mobility diameter; the difference was significant for $NaHCO_3$ but not for corn starch.

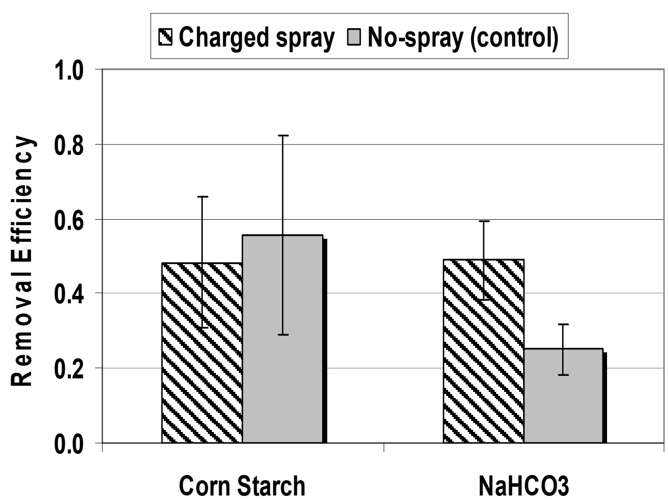

Figure 3. Removal efficiencies (mass basis) of the charged-water spray for the small particles (20 to 835-nm mobility diameter) for corn starch and $NaHCO_3$. Particle concentration was measured by the Scanning Mobility Particle Sizer™ spectrometer. Error bars represent one standard deviation.

Effects of spray duration, spray method, charge polarity, and relative humidity

Figures 4 and 5 compare the three spray durations in terms of the removal efficiency of the charged-water spray. For corn starch, the removal efficiency ranged from negligible for small particles to more than 90% for the large particles. For $NaHCO_3$, on the other hand, the removal efficiency was greater than 55%, even for the small particles. Table 3 compares the three spray durations in terms of η_{10} and $\eta_{2.5}$. As expected, longer spray durations (i.e., 4 and 6 min), which have greater mass of water sprayed, had significantly ($P<0.05$) higher dust-removal efficiency than the shorter spray duration (i.e., 2 min). In general, the 4- and 6-min spray durations did not significantly differ ($P>0.05$).

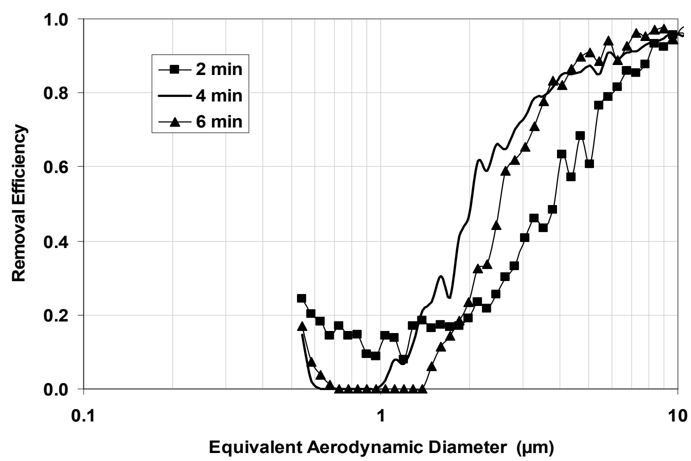

Figure 4. Removal efficiencies (mass basis) for corn starch of charged-water spray with spray durations of 2, 4, and 6 min. Particle concentration was measured by the Aerodynamic Particle Sizer™ spectrometer.

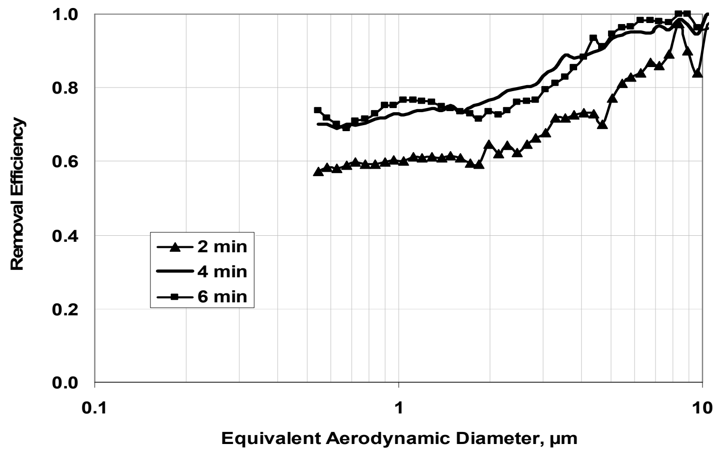

Figure 5. Removal efficiencies (mass basis) for $NaHCO_3$ of charged-water spray with spray durations of 2, 4, and 6 min. Particle concentration was measured by the Aerodynamic Particle Sizer™ spectrometer.

Table 3. Effect of spray duration on removal efficiency of charged-water spray.[1]

Spray Duration (min)	Corn Starch				$NaHCO_3$			
	η_{10}		$\eta_{2.5}$		η_{10}		$\eta_{2.5}$	
	Mean[2]	SD	Mean[2]	SD	Mean[2]	SD	Mean[2]	SD
2	0.84 b	0.02	0.18 b	0.10	0.76 b	0.05	0.61 b	0.04
4	0.92 a	0.02	0.33 a	0.08	0.88 a	0.03	0.70 ab	0.07
6	0.90 a	0.05	0.15 b	0.05	0.89 a	0.03	0.74 a	0.04

[1]Particle concentrations were measured with the Aerodynamic Particle Sizer™ spectrometer.
[2]Column means followed by the same letter are not significantly different at 5% level of significance.

Figures 6 and 7 compare the continuous and intermittent sprays. The intermittent spray generally resulted in slightly greater removal efficiencies than the continuous spray, but the two spray methods did not significantly differ ($P>0.05$) in removal efficiencies.

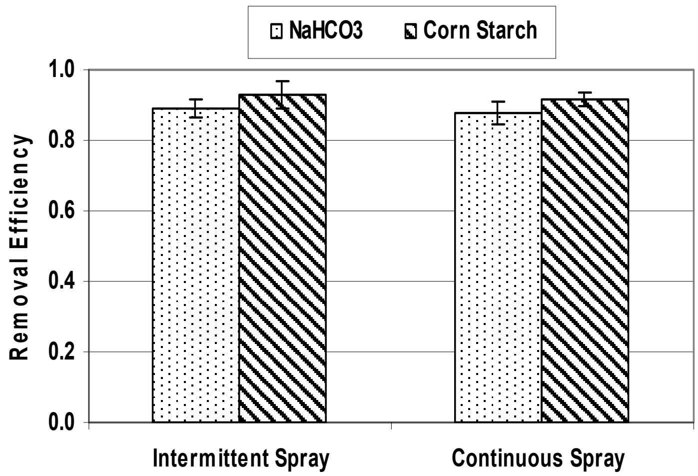

Figure 6. Removal efficiencies (mass basis) for particles ≤ 10 μm equivalent aerodynamic diameter for the continuous and intermittent charged sprays. Particle concentration was measured by the Aerodynamic Particle Sizer™ spectrometer. Error bars represent one standard deviation.

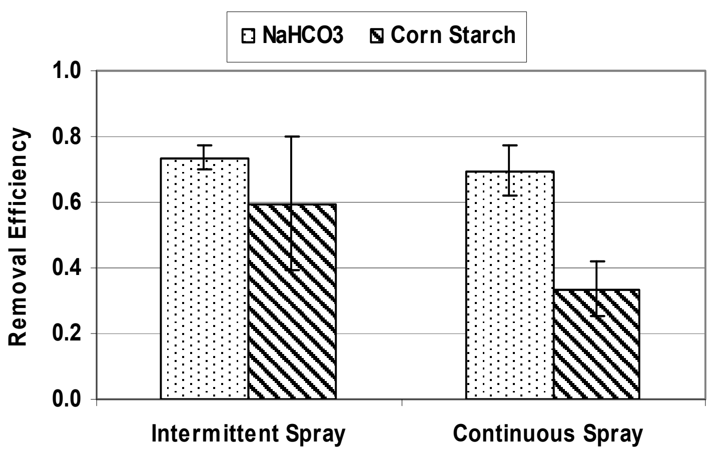

Figure 7. Removal efficiencies (mass basis) for particles ≤ 2.5 μm equivalent aerodynamic diameter for the continuous and intermittent charged sprays. Particle concentration was measured by the Aerodynamic Particle Sizer™ spectrometer. Error bars represent one standard deviation.

Table 4 summarizes the removal efficiencies for the negatively charged and positively charged sprays. The two spray polarities did not significantly differ ($P>0.05$) in $\eta_{2.5}$ for both powders; however, they significantly differed ($P>0.05$) in η_{10} for $NaHCO_3$.

Table 4. Effect of charge polarity on removal efficiency of charged-water spray.

Charge polarity	Corn Starch				$NaHCO_3$			
	η_{10}		$\eta_{2.5}$		η_{10}		$\eta_{2.5}$	
	Mean[1]	SD	Mean[1]	SD	Mean[1]	SD	Mean[1]	SD
Positive	0.91 a	0.07	0.47 a	0.04	0.83 a	0.02	0.66 a	0.03
Negative	0.92 a	0.02	0.34 a	0.09	0.88 b	0.03	0.70 a	0.08

[1]Column means followed by the same letter are not significantly different at 5% level of significance.

Table 5 compares the two levels of ambient relative humidity (40% and 80%). In general, removal efficiency was lower for the 80% relative humidity than for the 40% relative humidity. For $NaHCO_3$, the difference between the two humidities was not significant ($P>0.05$); for corn starch, on the other hand, the difference was significant ($P<0.05$).

Table 5. Effect of ambient relative humidity on removal efficiency of charged-water spray.

Relative humidity	Corn Starch				$NaHCO_3$			
	η_{10}		$\eta_{2.5}$		η_{10}		$\eta_{2.5}$	
	Mean[1]	SD	Mean[1]	SD	Mean[1]	SD	Mean[1]	SD
80 %	0.87 a	0.02	0.03 a	0.03	0.83 a	0.03	0.61 a	0.06
40 %	0.92 b	0.02	0.34 b	0.09	0.88 a	0.03	0.70 a	0.08

[1]Column means followed by the same letter are not significantly different at 5% level of significance.

Conclusions

The effectiveness of electrostatic-charged-water spray in reducing dust concentration in enclosed spaces was evaluated. The following conclusions were drawn from this research:

1. The electrostatic-charged-water spray was significantly more effective than either the uncharged-water spray or no-water spray. For particles ≤10 μm equivalent aerodynamic diameter, the mean (mass) removal efficiencies for the charged-water spray treatment (4-min spray duration) were 88% for $NaHCO_3$ and 92% for corn

starch particles. For particles ≤2.5 μm equivalent aerodynamic diameter, the mean mass removal efficiencies were 70% for $NaHCO_3$ and 34% for corn starch.

2. Longer charged-water spray durations (4 and 6 min) resulted in significantly higher particle-removal efficiency than the shorter (2 min) duration.
3. The method of spraying charged-water (i.e., continuous vs. intermittent) did not significantly influence particle-removal efficiency.
4. The charge polarity did not significantly influence particle-removal efficiency.
5. Particle-removal efficiency was generally higher for the low-ambient relative humidity (40%) than for the high relative humidity (80%).

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ASSESSMENT OF FOOD RESIDUALS FOR BIONERGY GENERATION

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Abstract
An analysis was conducted to evaluate the potential for biomass-to-energy conversion using residual food streams in the area encompassed by a 50-mile radius from the state capital, Sacramento, California. Selected high-volume food processing and food preparation facilities were identified and interviewed in the Sacramento area. The survey teams approached 45 businesses and interviewed 41 managers or owners. They identified annual flows of 35,518 dry tons of high-moisture (greater that 55% water) food residuals; 16,368 dry tons of low-moisture (less than 55% water) food residuals; and wastewater streams containing 7,336 tons BOD_5 .The estimated amount of potential electricity production from the combined food residual streams is 4,734 kWh .The survey also revealed that 1197 dry tons of food residual waste presently entering the city of Sacramento's landfills could be diverted and used for bioenergy production.

Key words: food leftovers, food processing waste, biogas, renewable energy

Introduction

Food scraps and food processing wastes can be used as substrates for bioenergy production. In California, food and processing residues accounted for about 4 million metric tons dry matter annually (Matteson and Jenkins, 2005). About half of this amount is likely available for utilization for bioenergy production. About two-thirds of the available waste streams have high-moisture content (> 50%, w.b.) that could support power generation by anaerobic digestion, ethanol fermentation, and thermal pyrolysis technologies. The remainder was characterized as low-moisture content streams that could be suitable substrates for power generation from direct combustion biomass power plants.

A program of the Sacramento Municipal Utility District (SMUD) aims at using waste and residues as a source for renewable energy production, while improving the environment and providing local economic benefits by diverting waste from landfilling and direct land application. A collaboration between University of California, Davis (UCD) and SMUD was established to survey and characterize the waste streams from local commercial food processors and institutions, including restaurants, bakeries, hospitals, and hotels, to better understand the availability of food waste for use in generating renewable energy.

The main objective of this study was to quantify the major food processing and municipal food waste streams in the Sacramento area. Different biomass-to-energy technologies are evaluated to define suitable technologies for each stream, so that it would be possible to estimate the level of biomass-to-energy conversions that can assist SMUD in meeting its Renewable Portfolio Standard of 12% of energy needs from renewable by 2006 and 23% by 2011.

Data Collection

The first step was to define the businesses, which have relatively high volumes of food residuals in the SMUD territories and within a 50-mile radius from the center of Sacramento. The 50-mile limit was selected because hauling costs beyond that distance make the electricity derived from biomass-to-energy conversion cost more than wholesale electricity (Jenkins et al., 1983).

The geographic distribution of the sites is 11 firms in the city of Sacramento, 21 firms in the SMUD and 45 firms within the 50-mile radius of the center of the city of Sacramento. An assessment of the food processing residues in the Sacramento area was conducted by phone interviews and, in some selected cases, on-site inspection and sampling. The annual production of waste streams and their characteristics were identified.

Waste Streams Characteristics

Waste streams were classified based on their moisture contents. Wastes with moisture contents (MC) of 55% wet basis or more in their typical production or handling state were denoted as high-moisture streams, and they were assumed to be converted using biochemical technologies (e.g. anaerobic digestion). Wastes with MC of below 55% were denoted as dry streams and were assumed to be converted using thermochemical methods (e.g. combustion). This classification is to some degree arbitrary, but reflects the practical limits on combustion above 60% moisture and the potential integration or expansion of existing waste treatment facilities for handling some materials (Jenkins and Ebeling, 1985).

Moisture data for the high-moisture food residuals were obtained from the plant managers or owners of the respective firms. Characterization of the waste streams from hospitals, schools, hotels, and medical care facilities was drawn from the managers and owners of the respective institutions. Then the values were reconfirmed and augmented by the values of Draper and Lennon (2001). Moisture content for the low-moisture food residuals was obtained from the plant managers or owners of the respective firms and then reconfirmed by values of Wiltsee (1993). For the sites that did not have records for the composition of their wastes/wastewaters, samples were collected for analyzing their moisture and organic matter contents according to the standard methods of the American Public Health Association (APHA, 1998).

Energy Potential Calculations

Based on the amounts and characteristics of waste/wastewater streams, estimates were made of the potential for generating electricity from these resources. In anaerobic digestion, the fraction of volatile solids in the total solids of the high-moisture wastes used was assumed to be 0.8, biodegradability was 0.67, intrinsic biogas yield was 0.75 $m^3\ kg^{-1}$ VS destroyed, methane concentration of biogas was 65%, and the engine -generator efficiency was 30%. The heating value of methane was 36.3 MJ m^{-3} at standard conditions (Matteson and Jenkins, 2005). The following equation was used to estimate the annual energy production from high-moisture waste streams:

$$E_{\text{annual}} = \frac{\phi_h \times \text{TS} \times VS \times \text{Bo} \times Y \times M \times CF \times \eta}{3600}$$

where:

E_{annual} = annual energy production (kWh),

φ_h = annual production of high-temperature waste stream (ton/year),

TS = total solids concentrations (kg/ton),

VS = volatile solids/total solids fraction (fraction),

Bo = anaerobic biodegradability (fraction),

Y = biogas yield (m^3/kg VS destroyed),

M = methane content (fraction),

CF = the caloric value of methane (kJ/m^3), and

η = generator efficiency (fraction).

For the digestion of wastewater, the annual energy production could be determined by the equation:

$$E_{\text{annual}} = \frac{\phi_w \times \text{BOD} \times 0.35 \times CF \times \eta}{3600}$$

where:

φ_w = annual wastewater production (m^3/year),

BOD = concentration of biological oxygen demand (kg/m^3), and

0.35 = a conversion factor: theoretical methane produced per kg BOD (m^3/kg).

For thermochemical conversion of low-moisture content streams, the efficiency was assumed to be 25% based on new biomass direct-combustion units operating in California (Matteson and Jenkins, 2005).

Survey Results

Tables 1, 2 and 3 show the annual production of waste stream and the power size from institutions that have high-moisture wastes, low-moisture wastes, and wastewater streams, respectively. As can be seen, the high-moisture waste, low-moisture waste and wastewater could deliver 2,982 kWe, 925 kWe, and 827 kWe, respectively. The major contributors of high-moisture streams are meat processing, wineries, and tomato canneries, with about 37%, 36%, and 21% of the total power, respectively. Fruit and vegetable waste and winery wastes represents about 52% and 40% of the total power that could be delivered from low-moisture waste streams. Tomato canneries represent about 43% of the total power that could be delivered from wastewater streams.

Criteria for Siting Biomass to Energy-Conversion Systems

The chosen facilities need to be in the SMUD, and energy generated must either reduce loads served by SMUD or fed into the SMUD grid. Centralized bioenergy production facilities (e.g. anaerobic digesters) are considered to combine different waste streams from up to 50 miles from the center of the city of Sacramento. Jenkins et al. (1983) modeled the best mix of biomass resources to provide minimum total delivered costs at a site and any size utilization facility at the site. Sensitivity to disposal tipping fees for in-vessel anaerobic digestion of food and other municipal residues has been described by Matteson and Jenkins (2005). Each $1.00/wet ton increase in the tipping fees results in a reduction of $0.005/kWh in the cost of energy.

Another criterion for siting a digester in Sacramento is the reduction of the food-residual stream to landfills. The number and types of solid-waste facilities in Sacramento were documented by Williams (2003). Most of the high-moisture food residuals and low-moisture food residuals from firms within the city limits of Sacramento are being deposited into landfills. The amount reflected in our surveyed firms is 1197 dry tons. This is about 4% of the landfilled "organics" observed by Williams (2003).

Certain economies of scale need to be accomplished when siting a bioenergy technology. The anaerobic digestion of high-moisture food residuals has been economically evaluated by Hartman (2004). He determined that 38 metric dry tons per day was the minimum level required to support the investment of about $1.8 million for an APS digester. There was a critical tipping fee avoided that led to this decision. The author assumed a very low tipping fee of $13.25 per ton in his model. Normal tipping fees for the Sacramento area start at $28 per ton.

Anaerobic Digestion Technologies

The choice of a certain anaerobic digester depends mainly on the characteristics, mainly moisture content, of the substrate(s) to be treated. Table 4 shows the common applied digesters for low-and high-moisture content substrates.

It is well known that temperature and mixing of anaerobic digesters are two important parameters that affect performance of the process. The anaerobic technologies can be applied with and without heating and mixing. The heated digesters could be operated at mesophilic temperatures (25-40^{o}C) or thermophilic temperature (>50^{o}C). Each of these temperature regimes has many advantages and drawbacks (Van Lier, 1995). Types of mixtures and their selection criteria are explained by Metcalf and Eddy (2003). Table 5 shows a comparison between the commonly applied anaerobic digestion systems and their suitability for different substrates.

Opportunities for the Application of Anaerobic Digestion Technologies

The firms most interested in siting a digester on their premises are those who can use the energy produced on site, either in the methane gas form or electricity. Therefore, the prices of purchasing these forms of energy could be avoided. The siting of the digester is ideally at a firm that has sufficient space. For example, a 5-ton/day anaerobic phased-solids dDigester (APS-Digester) requires about one acre for the truck access, unloading equipment, tanks, engine generator, and control house. Another requirement is the operation of a digester. Firms that would place a digester on site must make a choice between operating the unit with existing staff or leasing out the facility and having it operated by a developer.

The final consideration in siting the digester is the access to wastewater treatment of the liquid fraction of the digestate, and handling and utilization of the solid fraction. The water fraction from the digester may be sent to the municipal wastewater treatment plant. Since the water fraction is high in nutrients, it may be directed to land application. In dairy farms and the municipal wastewater treatment plant, a strategy to manage salt will be required. The solid fraction can be dried and sold as a soil amendment. The solid fraction could also be routed to a compost operation.

On-Site Digesters

Our inventory reveals there is only one on-site digester site that clearly meets the above siting requirements. It is a soup company that has a wastewater stream of 414 million-gallons /year with a BOD_5 concentration of 600 mg/l. The potential electricity generation capacity is 117 kWe. The company has the space for a covered lagoon. With annual electricity consumption of 36.5 million kWh costing $2.8 million, and a waste water treatment bill of $800,000 to $1 million, they are clearly in a position to benefit from this strategy.

Single On-Site Digesters for Treating Two or More Off-Site Feed Streams

There are a number of firms which might meet the site-selection criteria for placing an on-site digester on their premise and taking in feed streams of fairly similar materials. A soup company is a candidate for applying this system. While this firm only has 686 dry tons of food residuals a year, it has the space and access for multiple high-moisture food streams. Firms like Folsom State Prison could easily feed this facility with an additional 28 dry tons per year. The challenge is to reach levels of 11,000 dry tons per year. This may be an impossible task, since this survey only revealed 35,000 dry tons of high-moisture food residues in the 50-mile radius.

A vegetable produce distributor is another candidate digester. This firm does not have a large waste stream, only 69 dry tons per year, but they have a central location and on-site space. They also would benefit by using any on-site generated electricity. Their current electrical service is 15.5 kW, and their electricity bill ranges up to $28,000/ month.

Multiple On-Site Digesters Treating Multiple Types of Off-Site Feed Streams

Sacramento Wastewater Treatment is the only facility that has the capacity to handle a diverse stream of waste. This organization is already performing this task with the exception of the low-moisture food residues. Sacramento Wastewater Treatment uses the existing anaerobic digester to make methane. They then burn this methane in a generator to make electricity. The electricity is used to run the pumping system.

The transition from managing one's own waste stream to becoming a waste management facility can be a critical factor for siting a digester. Permitting beyond just the Integrated Waste Management Board may include air quality, water quality, and land use.

General Considerations of Anaerobic Digestion Application

A detailed economic analysis for each candidate listed above is required to compare the benefits of insulation of anaerobic digesters. The economics of a digester project can change dramatically if the energy cannot be used to offset the existing on-site load. As a rule of thumb, the project cash flows for grid feeds are about 50% of the avoided costs on a per-kWh basis. Air quality concerns, from operating electrical generators, a challenge for some sites, should be analyzed carefully. Upgrading the digester biogas by removing hydrogen sulfide and water vapor is crucial to use the biogas in internal combustion engines and turbines. Antagonistic and synergistic effects of digesting more than one substrate in the same digester should be addressed carefully. Management of salts and nutrients present in the digester effluent is an important issue, because most salts in digestate that is sent to ponds or land application go towards groundwater load (Harter and Menke, 2004). The digestate that goes to municipal wastewater treatment plants becomes a concern at the point of discharge to streams and rivers. Strategies such as reverse osmosis are used when wastewater approaches unacceptable limits.

Co-digestion means combining two or more substrates with similar or different physical and chemical compositions. It is possible to achieve higher rates of biogas production per unit of reactor volume provided the combination of the substrates will not affect the process stability (El-Mashad and Zhang, 2006). Therefore, better economics would be expected. However, co-digestion may require careful mixing of different streams. For example, introducing high concentration of protein could upset methanogenic bacteria via producing high concentration of ammonia during the hydrolysis step. Ammonia is believed one of the inhibitory compounds if its concentration exceeds certain thresholds that depend strongly on digestion temperature and acclimatization of methanogenic bacteria (Koster and Lettinga, 1984).

Conclusions

This study has identified some possible sites for biomass-to-energy conversion systems in the SMUD. Total potential electricity generation identified in this study was slightly more than 4.73 MW. The amount that is potential generated from the probable sites in the district which ranges from 149 kW (milk processor) to 156 kW (the soup company). Based on the characteristics of waste streams from these two sites, a lagoon digester and an APS-digester would be recommended. The single largest barrier to achieving high numbers in electricity production is the present regulatory barriers that damper owners' or plant managers' enthusiasm when it comes to co-digestion of multiple waste streams from off site. Management of salts and nutrients in the digestate may also prove to be challenging.

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Table 1. Sampled institutions having high-moisture waste streams.

No. of sites	Institution	Dry matter (ton/year)	Electricity generation capacity (kWe)	Fraction of total (%)
4	Meat processing	13263	1114	37.3
6	Wineries	12642	1061	35.6
4	Tomato canneries	7773	653	21.9
7	Fruit and vegetables distribution	802	67	2.3
4	Fruit canneries	632	53	1.8
2	Schools and prisons	309	26	0.9
2	Healthcare	67	6	0.2
3	Hotel	31	3	0.1
	Total	35518	2982	100.0

Table 2. Sampled institutions having low-moisture waste streams.

No of sites	Institution	Dry matter (ton/year)	Electricity generation capacity (kWe)	Fraction of total (%)
5	Fruit and vegetable	8484	484	51.8
1	Winery	6480	369	39.6
1	Cannery soup	686	39	4.2
1	Bakery	645	29	3.9
2	Meat processing	43	2	0.3
1	Grain and fiber processing	29	1	0.2
	Total	16368	925	100.0

Table 3. Sampled institutions having wastewater.

No. of sites	Institution	BOD_5 in wastewater (ton/year)	Electricity generation capacity (kWe)	Fraction of total (%)
3	Tomato canneries	3167	357	43.2
1	Milk processor	1318	149	18.0
2	Fruit canneries	1195	135	16.3
1	Cannery soup	1038	117	14.1
3	Vineyards	575	65	7.8
1	Meat processing	43	5	0.6
	Total	7336	828	100

Table 4. Example anaerobic digestion technologies for treating wastes/wastewaters.

High-moisture substrates (<10% dry matter)	Low-moisture substrates (over 10% dry matter)
- Covered lagoon digester - Completely mixed digester - Plug-flow digester - Anaerobic contact reactor - Upflow anaerobic sludge blanket reactor - Anaerobic sequencing batch reactor - Anaerobic filter - Anaerobic mixed-biofilm reactor	- Batch digester (landfill reactor) - Mixed digester - Plug-flow digester (e.g. Dranco) - Anaerobic phased-solids digester (e.g. APS-Digester)

Table 5. Comparison of different anaerobic digesters.

	Mixing /heating	Reaction rate	Total solids in feed		Ability of handling suspended solids
			1- 4%	4 -10%	
Covered lagoon	No	Low	Yes		High
Anaerobic contact reactor	Yes	High	Yes		High
Anaerobic filter	Yes	High	Yes		Low
Upflow sludge-blanket reactor	Yes	High	Yes		Low
Anaerobic fluidized bed reactor	Yes	High	Yes		Low
Anaerobic sequencing-batch reactor	Yes	High	Yes		High
Anaerobic mixed-biofilm reactor	Yes	High	Yes		High
Completely mixed reactor	Yes	High		Yes	High
Plug-flow digester	Yes/No	High		Yes	High

SOIL-EROSION ESTIMATION IN CONSERVATION TILLAGE SYSTEMS WITH POULTRY LITTER APPLICATION USING RUSLE 2.0 MODEL

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Abstract
Soil-erosion is a major threat to global economic and environmental sustainability. The objectivess of this study were to evaluate long-term effects of conservation tillage with poultry litter application on soil-erosion estimates in cotton (*Gossypium hirsutum* L.) plots using the RUSLE 2.0 computer model. Treatments consisting of no-till, mulch-till, and conventional tillage systems; winter-rye (*Secale cereale* L.) cover cropping and poultry litter; and ammonium nitrate sources of nitrogen were established at the Alabama Agricultural Experiment Station with and without winter-rye cover cropping, respectively. Application of N in the form of ammonium nitrate or poultry litter significantly increased cotton canopy cover and surface-root biomass, which are desirable attributes for soil-erosion reduction.

Key words*:* RUSLE 2.0, conservation tillage, cover crop, soil-erosion, C-factor

Introduction

Soil-erosion is associated with about 85% of land degradation in the world, causing up to 17% reduction in crop productivity (Oldeman et al., 1990). Despite more than 60 years of state and federal soil conservation efforts, soil-erosion remains a serious environmental problem in parts of the U.S. (Uri and Lewis, 1998). Worldwide, about 40% of agricultural land is seriously degraded (BBC News, 2000). In addition to land degradation, other problems caused by soil-erosion include loss of soil nutrients, declining crop yields, reduction in soil productivity, and pollution of surface and ground water resources by sediment, fertilizer nutrients, and pesticide residues.

Soil-erosion also causes air pollution through emissions of radiatively active gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Lal, 2001; Boyle, 2002). Increased concentration of CO_2, CH_4, and N_2O, also known as “greenhouse gases” in the atmosphere is associated with global warming, which leads to an increase in the earth’s temperature. Global warming may have far-reaching undesirable effects on weather patterns, forests, agriculture, and water supplies. This will affect the well being of humans and other living organisms.

Some fields in Alabama and Mississippi have been under conventional tillage cotton production for 100 years or more (Bauer and Black, 1983). Cotton is a low-residue crop. Therefore, monocropping cotton for an extended period of time has led to soil degradation on cotton farms (Reeves et al., 2002). Although conservation tillage cotton acreage nearly tripled in Alabama and Georgia between 1998 and 2002 (National Cotton Council of America, 2003), about 40 % of cotton acreage in north Alabama is still under conventional tillage. Conventional tillage cotton production systems typically include primary tillage with a moldboard or chisel plow in the fall, spring disking or harrowing, and inter-row cultivation for weed control during the crop growing season. These operations promote soil-erosion and rapid depletion of soil organic matter (Keeling et al., 1989; Bordovsky et al., 1998).

Conservation tillage systems such as no-till and mulch-till can reduce soil-erosion, conserve soil moisture, replenish soil organic matter, and improve crop yields in the long term (Tripplet et al., 1996; Reeves, 1997; Nyakatawa et al., 2001; Reddy et al., 2004). Conservation tillage is defined as any tillage and planting system that leaves at least 30% of crop residues on the soil surface after planting (CTIC, 1998). A cover crop, usually grown in winter, is often required to achieve this level of residue cover. In addition to being a low-residue-producing crop, cotton leaves have lower mulch persistence compared to grass species. It is therefore important to use a suitable cover crop to increase residue production, which will reduce soil-erosion in cotton production systems. Winter-rye [*Secale cereale* (L.)] possesses many desirable characteristics to be used as a cover crop in cotton production. These include its effectiveness in reducing leaching losses of residual nitrogen, high vigor, winter hardness, early spring growth, and good herbicide sensitivity, which enables it to be killed in time for cotton planting.

In addition to being a relatively cheap source of both macro- and micronutrients, animal manure can improve soil tilth due to addition of soil organic matter and enhanced soil microbial activity. Soil organic matter impacts all soil quality functions and soil chemical, biological, and physical properties which improve soil resistance to erosion. Poultry litter is available in abundant quantities in the southeast U.S. and its disposal is becoming a problem. Therefore, the use of poultry litter in cotton production serves both as a sustainable utilization of a renewable nutrient resource and also, as an environmentally sound method for disposing of animal waste. The objectives of this study were to investigate the long-term effects of no-till and mulch-till conservation tillage systems with winter-rye cover cropping and poultry litter application on soil-erosion in cotton plots using the Revised Universal Soil-Loss Equation (RUSLE 2.0) computer model.

Materials and Methods

Study site and treatments

The experiment was established at the Alabama Agricultural Experiment Station, Belle Mina, Ala. (34^0 41' N, 86^0 52' W), on a Decatur silt-loam soil (clayey, kaolinitic thermic, Typic Paleudults) in fall 1996. The study site has a slope of about 1.5% and had been cultivated with cotton under conventional tillage and monocropping for more than 10 years prior to the establishment of this experiment. Treatments used in this study consisted of three tillage systems: conventional tillage, mulch-till, and no-till; two cropping systems: cotton in summer followed by winter-fallow and cotton in summer followed by winter-rye; three N levels: 0, 100, and 200 kg N ha^{-1}; and two N sources: ammonium nitrate and poultry litter. Due to space limitations and operational constraints such as labor and input costs resulting from a larger number of treatments, an incomplete factorial treatment arrangement consisting of 12 treatments was used (Table 1). Ammonium nitrate was used at one N rate (100 kg N ha^{-1}), which is the recommended rate for cotton in the Tennessee Valley region, while poultry litter was used at 100 and 200 kg N ha^{-1}. Plot size was 8-m wide and 9-m long, which resulted in eight rows of cotton, 1-m apart. The plots were arranged in a randomized complete block design with four replications.

Conventional tillage involved tilling the soil to a depth of 25-30 cm using a moldboard plow in November and disking followed by a field cultivator to prepare a smooth seedbed in April. In mulch-till, a Lely rotary cultivator (Lely USA Inc., Wilson, N.C.) was used to destroy and partially incorporate crop residues to a depth of 5 to 7cm before planting. No-till included planting into untilled soil using a Tye (Glascock Equipment and Sales, Veedersburg, Ind.) no-till planter. During the season, a row cultivator was used for controlling weeds in the conventional tillage system, while spot applications of glyphosate [*isopropylamine salt of N-(phosphonomethyl) glycine*] were used to control weeds in the no-till and mulch-till systems. A single operation of row cultivation and herbicide spray were used each year.

The poultry litter used in this study consisted of a combination of chicken (*Gallus gallus domesticus*) manure and bedding materials brought from nearby poultry farms. Amounts of poultry litter to supply 100 and 200 kg N ha^{-1} were calculated for application each year based on the N content of the poultry litter. Total N content of poultry litter was determined by the Kjeldhal wet-digestion method (Bremner and Mulvaney, 1982) and followed by N analysis using the Kjeltec 1026 N Analyzer (Kjeltec, Sweden) in 1997 and 1998; LECO CNS analyzer (St. Joseph, Mich.) in 2000 and 2001; and the Vario MAX CNS macro elemental analyzer (Elementar Analysensysteme, GmbH, Germany) in 2003 and 2004. Poultry litter was not applied to the plots in 1999 and 2002, which were planted with corn. A 60% adjustment factor was used to compensate for N availability from poultry litter during the first year (Keeling et al., 1995). The litter was broadcast by hand and incorporated to a depth of 5- to 8 cm by pre-plant cultivation in conventional tillage and mulch-till systems, whereas in the no-tillage system it was surface applied and not incorporated. The ammonium nitrate and poultry litter were applied to the plots 1 d before cotton planting. Prior to planting, the plots received a blanket application of a P and K fertilizer each year based on soil analyses results, to minimize the effects of P and K applied through poultry litter.

The cropping scheme showing summer rotation of cotton with corn and winter-rye cover crop used in this study is presented in Table 2. The winter-rye cover crop was planted in fall and killed with glyphosate herbicide about 7 d after flowering in spring of 1997, 1998, 2000, 2001, 2003, and 2004. The time between killing of winter-rye and cotton planting was about four weeks in each year. The winter-rye cover crop (cv. Oklon) was planted at a seeding rate of 60 kg ha^{-1} using a no-till grain drill. The cover crop did not receive any fertilizer to enable it to “scavenge” residual soil nutrients and incorporate them as aboveground biomass during the winter season, which reduces runoff and/or leaching losses of N.

Soil-erosion estimation

Soil-erosion estimation was done using the Revised Universal Soil Loss Equation (RUSLE 2.0) computer model by plot each year in 1997, 1998, 2003, and 2004. RUSLE is an empirically based model founded on the universal soil loss equation – USLE (Wischmeier and Smith, 1978). Renard et al. (1997) modified USLE and developed RUSLE, which has improved means of computing soil-erosion factors. The RUSLE model enables prediction of an average annual rate of soil-erosion for a site of interest for any number of scenarios involving cropping systems, management techniques, and erosion-control practices.

RUSLE model structure

The RUSLE computer model incorporates four physical parameters associated with erosion by water, namely rainfall erosivity, soil erodibility, topography, and land-use management. Detailed description of the model is presented in Nyakatawa et al. (2001). In RUSLE 2.0 software, information is organized into five main databases, namely climate, soil, management, vegetation, and residue. The latest version of RUSLE model software (RUSLE ver. 2.0) has revised governing equations and an updated database (Bonorino and Osterkamp, 2004).

RUSLE model C-factor *input plant data collection*

Immediately after cotton planting, surface residue cover (SRC) in each plot was measured using the camline transect method (Renard et al., 1997). Cotton plant growth data collected for the RUSLE C-factor calculation were canopy cover, fall height from the crop canopy, and surface-root biomass (top 10 cm of the soil) (RUSLE Users' guide, 2003). Detailed description of data collection methods is given in Nyakatawa et al. (2000; 2001). The data for RUSLE C-factor input data calculation were taken every 15 days until crop harvest as per model requirements. In addition to plant data collected for the RUSLE C-factor input data given above, biomass data for winter-rye, cotton, and corn crops were collected and used in the residue database to account for their contribution to crop residues. RUSLE also requires crop yield data, which was determined by mechanically harvesting open cotton bolls in the central four rows of each plot using a mechanical stripper. Data for cotton yield from this study has been published in Nyakatawa et al. (2000; 2001) and Reddy et al. (2004).

Weather data for R-factor calculation

Daily weather data needed to calculate the R-Factor were taken from an automatic weather station at the experiment station. The data consisting of rainfall temperature data

(Fig. 1) were entered into the RUSLE model city database to calculate the R-factor for the study location.

Statistical data analyses

The data were statistically analyzed using general linear model procedures of the Statistical Analysis System (SAS ver. 9.1). Due to incomplete factorial treatment arrangement used in the study, treatments 2, 3, 4, and 8 were analyzed separately to evaluate tillage x cropping system interaction. Similarly, treatments 4, 5, 6, 7, 8, and 9 were analyzed separately to evaluate tillage x N source interaction. Treatment means for main effect of tillage systems, main effect of cropping systems, and tillage x N source interaction were compared using the least-significant difference (LSD) mean separation procedure. Duncan's multiple-range test was used to statistically separate the full set of treatment means, which were used to make specific treatment mean comparisons. Correlation analysis was used to determine the association of SRC, EFH, and crop biomass to RUSLE C-factor values and soil-erosion estimates. Unless indicated otherwise, significant differences between treatment means were tested at $P < 0.05$ level.

Results and Discussion

RUSLE C-factor and soil-erosion estimates

There was a significant year x tillage x cropping system interaction on RUSLE C-factor values and a significant ($P < 0.001$) tillage x cropping system interaction on soil-erosion estimates (Table 3). RUSLE C-factor values for cotton-winter-rye cropping system under conventional tillage system were 85%, 107%, 134%, respectively, lower than those for cotton-winter-fallow cropping system, respectively in 1998, 2003, and 2004 (Table 3). Soil-erosion estimates in cotton winter-rye cropping system were 38%, 78%, 105%, and 135%, respectively, lower than those in cotton winter-fallow cropping system under conventional tillage system, in 1997, 1998, 2003, and 2004 (Table 3). These data show that winter-rye cover crop has progressively reduced C-factor values and soil-erosion estimates from 1997 to 2004.

With the exception of 2003, there were no significant differences in RUSLE C-factor values and soil-erosion estimates between cotton winter-fallow and cotton winter-rye cropping systems under no-till system. Our results are similar to those of Yoo and Touchton

(1989) and Yoo and Rochester (1989), who reported that use of wheat cover crop in no-till cotton did not significantly reduce soil loss compared to no-till without a cover crop, but both had lower soil loss than conventional tillage. Stevens et al. (1992) reported that without cover cropping, no-till can reduce soil-erosion by 70% compared to conventional-till system in cotton.

The pattern of decline in RUSLE C-factor values and soil-erosion estimates with time from 1997 to 2004 was not observed under cotton winter-fallow cropping system in a conventional tillage system or in a no-till system. These results can be expected and can be explained by the fact that in conventional till and cotton winter-fallow cropping system, there were no additional crop residues to supplement those produced by cotton. Also, additional crop residues from cotton winter-rye cropping system in a no-till system do not impact soil-erosion rates as much as they do in a conventional tillage system.

RUSLE C-factor values in bare fallow plots were, on average, two and four times, respectively, greater than those in cotton winter-fallow and cotton winter-rye cropping systems under a conventional tillage system (Table 3). Similar values under a no-till system were five and 52 times greater, compared to those in cotton winter-fallow and cotton winter-rye cropping systems, respectively. In a conventional tillage system, mean soil-erosion estimate in cotton winter-fallow cropping system over the study period (11.4 Mg ha^{-1} yr^{-1}) was about 50% that for bare fallow plots (24.5 Mg ha^{-1} yr^{-1}). Soil-erosion estimates in a cotton winter-rye cropping system was 6.2 Mg ha^{-1} yr^{-1} or about 25% that for bare fallow plots. In a no-tillage system, similar values were 5% and 7%, respectively.

There was a significant tillage x N source interaction for RUSLE C-factor values and soil-erosion estimates. In a conventional tillage system, RUSLE C-factor values and soil-erosion estimates for plots which received 100 kg ha^{-1} in the form of ammonium nitrate (100AN) were 15% and 32%, respectively, lower than those for plots which received the same amount of N in the form of poultry litter (100PL) (Fig. 2). However, there were no significant differences in RUSLE C-factor values between sources of N.

RUSLE C-factor input data

Results for RUSLE C-factor values and soil-erosion estimates presented and discussed above can largely be explained by the responses of RUSLE C-factor input variables to crop and soil-management strategies in different plots. While most of the information required for predicting soil-erosion using RUSLE, such as rainfall and soil data do not vary much from plot to plot, the C-factor responds directly to yearly variations in crop production systems, such as residue, soil-management practices, and tillage systems. The RUSLE C-factor accounts for the interactive effects of soil cover, cropping sequences, cultural practices, and length of growing season on the soil-erosion process. Responses of RUSLE C-factor input variables (surface residue cover, cotton canopy cover, effective fall height, and cotton-surface-root biomass) to tillage systems, cropping systems, and N treatments used in this study and their influence on RUSLE C-factors and soil-erosion estimates are discussed in the following sections.

Surface residue cover (SRC)

There was a significant year x tillage x cropping system interaction on percent surface residue cover (SRC) after cotton planting (Table 4). Each year, in conventional tillage or no-till system, SRC in plots which had rye cover crop in the previous winter, was significantly greater than that in plots which were fallow in the previous winter (Table 4). By definition, at least 30% of the soil surface has to be left covered with crop residues after planting in order for any tillage system to be considered as conservation tillage (Conservation Tillage Information Center, 1994). In 1997 and 1998, conventional tillage had less than 30% SRC with or without winter-rye cover crop. However, it is interesting to note that in 2003 and 2004, SRC in conventional tillage system in plots which had winter-rye cover crop was 30% and 37%, respectively, which enabled conventional tillage with winter-rye cover cropping to qualify to be considered as conservation tillage.

Visual records showed that crop residues from the rotational corn crop of 1999 were still present in the plots in 2000 and 2001, while crop residues from the corn crop of 2002 were still present in all plots in 2003 and 2004. This explains the increase in surface-residue cover in conventional till with winter-rye cover cropping and in no-till with winter-fallow cropping (1997 and 1998 vs 2003 and 2004) as shown in Table 4. Halvorson et al. (2002) also found that surface-crop residues increased with time under no-tillage with corn rotations due to carry-overs from year to year, but their findings were in a drier, cooler climate in Colorado. It is interesting that we found similar results in a thermic, humid regime.

There was no improvement in SRC in conventional tillage with winter-fallow cropping to enable it to qualify as conservation tillage. Leaving the plots fallow in winter does not provide the additional crop residues needed to increase SRC. The 6% to 7% decline in SRC in no-till system with winter-rye cover cropping in 2003 and 2004 compared to 1997 and 1998 (Table 4) was attributed to poor winter-rye cover crop growth in 2003 and 2004, which was up to 50% lower than that for 1997 and 1998. Carry-over of crop residues from the corn crop of 2002 resulted in significantly greater figures for SRC in conventional tillage with winter-fallow cropping (2003) and no-till system with winter-fallow (2003 and 2004).

Other benefits of leaving crop residues on the surface after planting include increased water infiltration into the soil and moisture conservation in the seed zone. Naderman (1991) reported that surface residue potentially increases infiltration of water into the soil by 25% to 50% under no-till compared with a conventional tillage system. Other researchers found that cover crop residues decrease the effect of wind and temperature on soil-water evaporation and increases water storage in the soil profile (Smart and Bradford, 1996). Nyakatawa and Reddy (2000) found 38% and 56% increase in soil moisture content in the seedzone during the first four days of seedling emergence due to winter-rye cover cropping, respectively, in conventional tillage and no-till systems.

According to Moldenhauer et al. (1983), a minimum of 20% soil-surface cover is required for a substantial reduction in soil-erosion. Also, as SRC approaches 100%, soil-erosion declines to a figure close to zero (Moldenhauer and Langdale, 1995). Surface residue intercepts raindrop-impact energy and reduces the flow velocity of runoff water, thereby minimizing soil-erosion, detachment, and transport processes (Cruse et al., 2001). Pimentel (1993) concluded that the cover-management factor is the most important factor in minimizing the soil-erosion rate.

In our study, SRC was negatively correlated ($P < 0.001$) to RUSLE C-factor values and soil-erosion estimates (Table 5). Having more crop residues left on the soil surface after planting resulted in reduced soil-erosion estimates since the soil is protected from the erosive force of the impact of raindrops and to that of running water. It is evident from Table 5 that the magnitude of the negative correlations between SRC and RUSLE C-factor values and soil-erosion estimates increased with time from 1997 to 2004, showing a cumulative effect of

SRC with time. Therefore, the progressive decline in RUSLE C-factor values and soil-erosion estimates in cotton winter-rye cropping system under conventional tillage from 1997 to 2004 can largely be attributed to cumulative effects of crop residues on SRC. According to Shelton et al. (1990), surface residue cover serves as a measure of the susceptibility of a field to soil-erosion, and is a function of the amount and persistence of crop residue present on the soil surface. Our results demonstrate the important role of SRC in soil and crop-management strategies designed to reduce soil-erosion in cotton production systems.

Canopy cover

There was a significant year x N source interaction on cotton-canopy cover measured at boll maturity (Data not shown). With the exception of 1998, canopy cover for cotton plants in plots which received 100 kg ha^{-1} in the form of ammonium nitrate and 200 kg ha^{-1} in the form of poultry litter (200PL) were significantly higher than that for plants in plots which received 100 kg ha^{-1} in the form of poultry litter. Figure 3 shows that during the first 45 days after cotton emergence, canopy cover was similar in all plots irrespective of N source. Therefore, during this time, crop residues left on the surface after planting play a very important role in soil-erosion reduction. However, from 60 to 120 days after emergence, cotton-canopy cover in plots which received 100 kg ha^{-1} in the form of ammonium nitrate or poultry litter and 200 kg ha^{-1} in the form of poultry litter (200PL) were consistently greater than that for plants in plots which did not receive N.

Differences in crop responses to 100 kg ha^{-1} in the form of ammonium nitrate and 100 kg ha^{-1} in the form of poultry litter, although not significant, were attributed to differences in N availability between ammonium nitrate and poultry litter. Crop residues can cause immobilization of available inorganic N (Green et al., 1995). Application of N in the form of ammonium nitrate can offset the effects N immobilization, whereas more time is needed for N to be released when N is applied in the form of poultry litter. A similar result was obtained in cotton-yield responses from ammonium nitrate and poultry litter (Nyakatawa et al., 2000, 2001; Reddy et al., 2004). Although a correction factor was used to account for the slow release of N from poultry litter, it does seem that the availability of N from poultry litter was over-estimated in these situations where considerable surface residues are present as shown by the better response of the crop to poultry litter at 200 kg N ha^{-1}. In Georgia, Endale et al.

(2002) reported no significant differences in cotton yields between poultry litter and inorganic fertilizer.

Unlike crops such as cereals and grain legumes, cotton is generally planted in wide rows of about 1m apart. This leaves most of the inter-row spacing exposed to direct impact of raindrops, especially early in the growing season. Energy from the direct impact of raindrops on the soil surface is a major factor causing disintegration of soil structure and the break up of soil particles generating sediment. Therefore, establishment of a widely distributed crop-canopy cover is very critical for cotton in terms of soil-erosion reduction. A good canopy cover gives soil better erosion protection by absorbing the energy from falling raindrops from rainfall or irrigation, which accounts for most of the erosion. Since cotton canopy cover was negatively correlated ($P < 0.001$) with RUSLE C-factor values and soil-erosion estimates (Table 5), better canopy growth accounts for the significantly lower RUSLE C-factor values and soil-erosion estimates for plots which received 100 kg ha^{-1} in the form of ammonium nitrate compared to those for plots which received the same amount of N in the form of poultry litter.

Effective fall height (EFH)

Effective fall height (EFH) for cotton, which is the distance a raindrop falls after striking the crop canopy, was negatively correlated to RUSLE C-factor values and soil-erosion estimates (Table 5). This should not be interpreted to suggest that with greater EFH, soil-erosion becomes less. Rather, it is a result of the fact that plots in which cotton plants performed better in terms of growth parameters such as plant height and biomass due to factors like no-till and cover cropping, also had low values of RUSLE C-factors and hence soil-erosion rates. There were no significant tillage or cropping system effects on EFH. However, from 60 to 120 days after emergence, EFH for cotton plants in plots which received 100 kg ha^{-1} in the form of ammonium nitrate and 200 kg ha^{-1} in the form of poultry litter were generally greater than that for plants in plots which did not receive N and sometimes, those which received 100 kg ha^{-1} N in the form of poultry litter (Fig. 3). However, despite the greater EFH in plots which received 100 kg ha^{-1} in the form of ammonium nitrate compared to those which received the same amount of N in the form of poultry litter, RUSLE C-factors and soil-erosion estimates were significantly lower in the former. This shows that the benefits of better plant growth such as better canopy cover and plant biomass in plots which received 100 kg ha^{-1} in the form of ammonium nitrate, out-weighed the increase in soil-erosion due to higher values of EFH.

Surface-root biomass

RUSLE 2.0 computer model requires data for surface-root biomass (top 10 cm of the soil) every 15 days as input data for the C-factor calculation. There was a significant effect of cropping systems and significant year x tillage and year x N source interactions on surface-root biomass of cotton (data not shown). Mean cotton surface-root biomass for in cotton winter-rye cropping system (2.3 Mg ha^{-1}) was 28% greater ($P < 0.005$) than that in cotton winter-fallow cropping system (1.8 Mg ha^{-1}) due to added biomass of cover crop. In 1997, mean cotton-surface-root biomass in no-till plots was 18% greater than that in a conventional tillage system. However, in 1998, mean cotton surface-root biomass in a no-till system was 30% lower than that in a conventional tillage system; while in 2003 and 2004, there were no significant differences in mean cotton surface-root biomass in no-till and conventional tillage systems.

As with a canopy cover, in terms of soil-erosion control, the rate of development of root biomass with time from seedling emergence is more important than the final root biomass at maturity in cotton, since the soil is more susceptible of erosion during the early stages of crop growth. Figure 3 shows the response of cotton-root biomass in the top 10 cm of the soil to N sources at 15 day intervals after seedling emergence. From about 75 to 120 days after emergence, cotton surface-root biomass for plants in plots which received 100 kg N ha^{-1} in the form of ammonium nitrate and those which received 200 kg N ha^{-1} in the form of poultry litter was greater than that for plants in plots that did not receive N and afrom 105 to 120 days after emergence, greater than those which received 100 kg N ha^{-1} in the form of poultry litter (Fig. 3). As with canopy cover and EFH, differences in crop response to 100 kg N ha^{-1} in the form of ammonium nitrate and 100 kg N ha^{-1} in the form of poultry litter can be attributed to differences in N availability between ammonium nitrate and poultry litter, as explained earlier.

Plant roots can physically hold soil particles together. In addition, roots and crop residues exude binding agents and serve as a food source of microbes, which increase soil aggregation and thereby reduce runoff. Plant roots can greatly enhance soil stability and anti-erodibility (Zhou and Shangguan, 2005). Cotton surface-root biomass was negatively correlated ($P < 0.001$) to RUSLE C-factor values and soil-erosion estimates (Table 5). Therefore, crop and soil management strategies which result in the rapid development of surface roots, will reduce soil loss by erosion. Table 5 shows that RUSLE C-factor values and soil-erosion estimates were negatively correlated to cotton biomass in each year and to winter-rye biomass in 1998, 2003, and 2004. The non-significant correlation between winter-rye biomass and RUSLE C-factor values and soil-erosion estimates in 1997 was attributed to the fact that winter-rye biomass data for 1997 was for the crop that was planted in fall 1996 before the establishment of the treatments. As a result, winter-rye biomass data were similar for all the treatments in 1997.

Conclusions

Our study shows that continuous additions of crop residues are critical for reducing soil-erosion and to increase the sustainability of cotton production in the southeast U.S., particularly in a conventional tillage system. Based on RUSLE 2.0 model predictions, soil-erosion estimates in a no-till system were significantly lower than those in conventional tillage, with or without winter cover cropping. Application of N in the form of ammonium nitrate or poultry litter significantly increased cotton-canopy cover and surface-root biomass, which are desirable attributes for soil-erosion reduction in cotton plots. Use of poultry litter as a source of N in cotton production systems may provide an environmentally sound strategy for waste disposal in the southeast U.S., where excess poultry manure is becoming an environmental problem.

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Table 1. List of treatments used in the erosion study at Belle Mina, AL, 1996-2004.

Trt. no.	Tillage system	Cropping system	N source	N rate (kg ha^{-1})
1	Conventional-till	Cotton/Winter-rye	None	0
2	Convention-till	Cotton/Winter-fallow	Ammonium Nitrate	100
3	No-till	Cotton/Winter-fallow	Ammonium Nitrate	100
4	Conventional-till	Cotton/Winter-rye	Ammonium Nitrate	100
5	Conventional-till	Cotton/Winter-rye	Poultry Litter	100
6	Mulch-till	Cotton/Winter-rye	Ammonium Nitrate	100
7	Mulch-till	Cotton/Winter-rye	Poultry Litter	100
8	No-till	Cotton/Winter-rye	Ammonium Nitrate	100
9	No-till	Cotton/Winter-rye	Poultry Litter	100
10	No-till	Cotton/Winter-fallow	None	0
11	No-till	Cotton/Winter-rye	Poultry Litter	200
12	Bare Fallow	Bare fallow	None	0

Table 2. Cropping scheme used in the erosion study, Belle Mina, Ala., 1996-2004.

Season	Year	Cropping System
Winter/Spring	1996/1997	Winter-rye
Summer	1997	Cotton
Winter/Spring	1997/1998	Winter-rye
Summer	1998	Cotton
Winter/Spring	1998/1999	Fallow
Summer	1999	Corn
Winter/Spring	1999/2000	Winter-rye
Summer	2000	Cotton
Winter/Spring	2000/2001	Winter-rye
Summer	2001	Cotton
Winter/Spring	2001/2002	Fallow
Summer	2002	Corn
Winter/Spring	2002/2003	Winter-rye
Summer	2003	Cotton
Winter/Spring	2003/2004	Winter-rye
Summer	2004	Cotton

Table 3. RUSLE model C-factor and soil-erosion estimates as influenced by cotton-winter-fallow and cotton-winter-rye cropping systems under conventional and no-till systems, Belle Mina Ala.

	Conventional tillage system		No-tillage system		Bare fallow
Year	Winter-fallow	Winter-rye	Winter-fallow	Winter-rye	
	C-factor				
1997	0.1405a†B‡	0.1500aA	0.0165aBC	0.0063aB	0.4500
1998	0.2450bA	0.1325aA	0.0121aC	0.0080aB	0.4500
2003	0.2025bAB	0.0976aB	0.0330bA	0.0082aB	0.4500
2004	0.2175bAB	0.0930aB	0.0215aB	0.0122aA	0.4500
	Soil-erosion estimate (Mg ha^{-1} yr^{-1})				
1997	11.0bA	8.0aA	0.9aB	0.4aA	26.0
1998	10.7bA	6.0aB	0.6aC	0.4aA	20.0
2003	11.7bA	5.7aB	2.2bA	0.6aA	28.0
2004	12.0bA	5.1aB	1.3aB	0.5aA	24.0

†Means for RUSLE C-factor or soil-erosion estimates under winter-fallow and winter-rye cropping system within a tillage system and year, followed by the same lower case letter, are not significantly different at the 5% level.

‡Means for RUSLE C-factor or soil-erosion estimates in different years within a tillage and cropping system, followed by the same upper case letter, are not significantly different at the 5% level.

Table 4. Surface residue cover after planting (SRC) as influenced by cotton-winter-fallow and cotton-winter-rye cropping systems under conventional and no-till systems, Belle Mina Ala..

	Conventional tillage system		No-tillage system	
Year	Winter-Fallow	Winter-Rye	Winter-Fallow	Winter-Rye
	SRC (%)			
1997	1a†B‡	20bB	17aD	100bA
1998	1aB	19bC	13aC	100bA
2003	13aA	30bAB	65aB	94bA
2004	6aAB	37bA	79aA	93bA

†Means for SRC for winter-fallow and winter-rye cropping system within a tillage system and year, followed by the same lower case letter, are not significantly different at the 5% level.

‡Means for SRC in different years within a tillage and cropping system, followed by the same upper case letter, are not significantly different at the 5% level.

Table 5. Pearson correlation coefficients (r) between crop growth parameters and RUSLE model C factor and soil-erosion estimates, Belle Mina, Ala., 1997–2004.

	Surface residue cover (%)	Canopy cover (%)	Effective fall height (cm)	Winter-rye biomass (kg ha^{-1})	Cotton-surface root biomass (kg ha^{-1})	Cotton biomass (kg ha^{-1})
	---------- C factor ----------					
1997	-0.61***	-0.78***	-0.37*	-0.24NS	-0.76***	-0.76***
1998	-0.68***	-0.76***	-0.75***	-0.44**	-0.58***	-0.62***
2003	-0.81***	-0.83***	-0.81***	-0.48***	-0.71***	-0.69***
2004	-0.84***	-0.74***	-0.79***	-0.39**	-0.77***	-0.78***
	---------- Soil-erosion estimate (Mg ha^{-1} yr^{-1}) ----------					
1997	-0.64***	-0.77***	-0.38**	-0.31*	-0.77***	-0.78***
1998	-0.68***	-0.76***	-0.74***	-0.43**	-0.58***	-0.62***
2003	-0.80***	-0.84***	-0.82***	-0.47***	-0.71***	-0.68***
2004	-0.84***	-0.74***	-0.78***	-0.39**	-0.77***	-0.78***

*, **, and *** significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Figure Captions

Figure 1. Total monthly rainfall and mean temperatures at Belle Mina, Ala., in 1997, 1998, 2003, and 2004.

Figure 2. RUSLE C-factor values and soil-erosion estimates as influenced by ammonium nitrate (AN) and poultry litter (PL) sources of N under conventional till (CT), mulch-till (MT), and no-till (NT) tillage systems, Belle Mina, Ala.; 1997-2004. (Means for RUSLE C-factors or soil-erosion estimates for N sources within a tillage system, followed by the same letter, are not significantly different from each other at the 5% level.)

Figure 3. Canopy cover, EFH, and cotton-surface-root biomass used as RUSLE C-factor input variables at 15-day intervals as influenced by N sources, Belle Mina, Ala.; 1997-2004 (LSD values of means shown).

REMEDIATION POTENTIAL FOR SITES CONTAMINATED WITH CARBON TETRACHLORIDE

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Abstract

Carbon tetrachloride (CT) has been used as fumigant in grain storage facilities. Remediation feasibility studies for a CT plume are being conducted by mesocosm experiments; a chamber is divided into six channels and filled with soil, and plants are grown on top. Each channel is fed with contaminated water near the bottom and the effluent is collected, simulating groundwater flow conditions. The contaminants were introduced starting from March 12, 2004. CT is introduced at a concentration of about 2 mg/L (~13 µmoles/L) in three channels, two of them with alfalfa plants and the other with fescue grass. Since no degradation was taking place, after about 100 days, one channel with alfalfa was fed one liter of 0.2% glucose solution. The glucose solution was fed once every month starting from July 1, 2004, and continued until February 2005. From October 1, 2004, one liter of 0.1% emulsified soy oil methyl esters (SOME) was fed to another channel (with alfalfa) exposed to CT. The SOME addition dates were the same as that for glucose. The outlet liquid of the channel fed with CT and SOME started to show some of the degradation compounds of CT; however, the extent of degradation was not as great as that of the glucose-fed channel. This study proved that the supplements glucose and SOME are effective substrates that can be added to CT-contaminated groundwater to achieve complete degradation of CT.

Key words: carbon tetrachloride, gluclose, soyoil methylesters

Introduction

Carbon tetrachloride (CT) is a solvent that has been used in the past as a cleaning fluid or degreasing agent, as a grain fumigant, and industrially in the synthesis of refrigeration fluid and propellants for aerosol cans. Degradation of carbon tetrachloride occurs slowly in the environment, which contributes to the accumulation of the chemical in the atmosphere as well as the groundwater (ATSDR, 2003). CT is, therefore, a common groundwater pollutant and a suspected human carcinogen. Although indigenous microorganisms may degrade CT, a common by-product is chloroform (CF), which may be more persistent than CT (Criddle et al., 1990a; Semprini and McCarty, 1992). Chloroform is a known degradation product of carbon tetrachloride and is readily formed under anaerobic conditions (Hull and Sondrup, 2003). The degradation products of CT (CCl_4), by reductive dechlorination, are chloroform (CF), methylene chloride (MC), and chloromethane (CM). Subsequent migration of the transformation products to an aerobic environment can lead to oxidation of the products with ultimate complete mineralization of the halogenated aliphatic compounds to chloride ion and carbon dioxide (Hull and Sondrup, 2003). Table 1 presents some of the important physical and chemical properties of CT and its degradation products. Numerous studies have illustrated that a potential exists for transformation of halogenated aliphatic compounds in groundwater under anaerobic conditions that are conducive to methanogenesis.

In this work, the degradation characteristics of carbon tetrachloride was studied in a six-channel, soil-column system. The degradation of CT is mainly limited by the availability of electron donors. Hence, two different substrates were used in this study to create the necessary reducing condition favorable for CT transformation.

Table 1. Physical/chemical properties[#] of CT and its degradation products.

Property\\Compound	CT	CF	MC	CM
Molecular weight	153.8	119.4	84.9	50.5
Boiling point (°C)	76.5	62	40	-23.8
Vapor pressure (mm Hg) at 25°C	115	195	447	4373
Dimensionless Henry's constant at 25°C (gas/liquid)	1.24	0.15	0.09	0.36
Density (gm/cc)	1.6	1.48	1.32	0.92
Solubility in water (g/L) at 25°C	0.8	8.1	20.0 (20°C)	6.3
$\log K_{oc}$	2.04	1.8	1.3	3.5
$\log K_{ow}$	2.83	1.97	1.3	0.91
MCL (maximum contaminant level) in water (μg/L)	5	100	5	NA

[#]Faris, 2002; Schwarzenbach et al., 1993; Spectrum Laboratories, 2006; Verschueren, 1996

Experimental System

Mesocosm: A chamber was divided into six channels; each channel was 110 cm long, 65 cm high and 10 cm wide. The channels were filled with soil (up to 60 cm); and alfalfa was grown in channels 1, 2, 5, and 6, while fescue grass was grown in channels 3 and 4 (Fig. 1). A pair of tubelights for each channel provided the light source for the plants. Channels 4, 5, and 6 were used for CT study. The inlet water was fed at 5 cm above the bottom of the channels (Figure 1). The contaminants were introduced starting from March 12, 2004. CT was introduced at a concentration of about 2 mg/L (~13 μmoles/L) in three channels, two of them with alfalfa plants and the other with fescue grass. The depth of saturated zone in the channel was controlled by position of the outlet tube (35 cm in this system). Plants were harvested at the beginning of each month. There were five monitoring wells (glass tubes with screening at the bottom) along the length of channel 6 with which groundwater samples could be collected from the bottom of the channel. The wells were placed at distances of 17, 35, 60, 73 and 100 cm from the inlet.

Biostimulation by Glucose and Soy Oil Methyl Esters

Since no degradation was observed after 100 days, supplements were added for growth of indigenous microbes, to create anaerobic conditions and also for supplying hydrogen. Introduction of 0.2% glucose solution as an electron donor into one channel (alfalfa grown on top, channel 5) resulted in anaerobic conditions in the channel. The glucose solution was fed once every month starting from July 1, 2004, and continued until February 2005. From October 1, 2004, one liter of 0.1% emulsified soy oil methyl esters (SOME) was fed to another channel (with alfalfa).

Analytical Method

Chlorinated compounds and methane were measured by gas chromatography (HP 5890 Series II, Wilmington, DE) equipped with a flame ionization detector (FID) and an HP-1 column (dimethyl polysiloxane matrix, 30 m x 0.53 mm, Agilent Technologies). Hydrogen was the carrier gas. The injector temperature was set at 200˚C and detector temperature was set at 300˚C. Sample volume of 100 μl was injected in the column at 100˚C and run for 5 minutes.

Results and Discussion

Inlet Outlet Analysis

Figures 2, 3, and 4 show the inlet CT, outlet CT, and degradation compound concentrations for channels 4, 5, and 6. Where no hydrogen donor was added (Figure 2), no degradation compounds were detected in the outlet and almost all inlet CT came out in the effluent.

Figure 3 shows the CT degradation in the glucose-treated channel. One liter of 0.2% (w/v) glucose solution was added every month starting from day 110 (June 30, 2004) until day 236 (November 3, 2004). On days 266, 299, and 328, corn starch solution (1 L of 0.2 % w/v) was added. Forty days after the first addition of glucose, the outlet CT started to decrease gradually and reached a low concentration (< 2 μM) by day 230. Chloroform appeared but never exceeded a concentration of 3 μM. Methylene chloride (MC) was also detected but remained less than 1 μM. Even after stopping the feeding of glucose (day 328), CT degradation continued. Glucose could be stored as polysaccharides and cell materials and released slowly to supply electron donors for dechlorination. Total chlorinated methanes (CMes) in the outlet dropped to about 2 μM by day 246 and remained at that concentration until day 500, and then started to increase due to lack of nutrients. After about day 600, the outlet CT concentration reached the value of inlet and remained constant until day 825, since no additional nutrients were added.

Figure 4 shows the CT degradation pattern in the SOME-fed channel. One liter of 0.1% (v/v) SOME was added every month starting from day 203 (October 1, 2004) until day 445 (May 31, 2005). Outlet CT decreased to low levels within 40 days after the first dose of the SOME addition, unlike the slow response in the glucose-amended channel. Chloroform (CF) was not detected above a concentration of 2.7 μM. However, methylene chloride (MC) increased and decreased regularly. This was due to the variation of the residence time of the inlet CT. During the starting of a month, the plants were harvested, and therefore, the evapotranspiration rate was less. In those days, most of the water flowed out and, therefore, the mean residence time was less. However, at the end of the month, when the plants were larger, the evapotranspiration rate was higher and the effluent was less. This led to higher mean residence times and, consequently, higher degradation of MC. In this channel, the inlet

CT was not completely degraded as in the glucose-fed channel. It was assumed that SOME, being hydrophobic, may adsorb to the soil organic matter at the initial portion of the channel and not be distributed along the length of the channel. Since electron donors were not available after well 1 (SOME sorbed between inlet and the first well), a dose of SOME [100 ml of 1% SOME (v/v)] was added to well 3 (60 cm from inlet) on day 445. After this addition, the total CMes in the outlet decreased drastically and remained less than 5 μM from day 550 to day 740, except for a couple of sampling dates. After day 750, the substrates were depleted and the concentration of CT started to increase at the outlet. However, it took up to day 825 for the concentration of CT in the outlet to reach the concentration of CT in the inlet.

Analysis of Well Samples

The schematic of the channel and the monitoring wells are shown in Figure 1. On day 438 (May 24, 2005), total chlorinated methanes (total CMes) in channel 6 decreased from ~12 μM to ~ 7 μM (Figure 5). Most of the inlet CT decreased (>80%) in the initial portion of the channel. Chloroform was formed, but the concentration was less than 1.5 μM and remained at that value throughout the length of the channel. Methylene chloride persisted in the channel and the outlet solution comprised mostly MC. Analysis of well samples on day 495 (July 21, 2005) revealed that this addition led to considerable decrease of MC in the outlet, 14 μM at well 3 to 2 μM at well 5 (Figure 6).

By day 741 (March 22, 2006), the SOME stored/sorbed in the channel was depleted and, therefore, the outlet CT increased (Figure 7). In the well samples, the concentration of CT was less compared to the outlet in Figure 7, and the total CMes in well 1 and well 2, compared to well 3 in Figure 6, because the sample may not have been representative of the channel water; the channel was 10 cm wide but the sample was collected from a 0.5-cm-diameter well.

Conclusions

Supplements such as glucose, corn starch, and SOME stimulated the indigenous microbes and helped in the degradation of CT. However the pattern and rate of degradation of CT were different due to different supplements. As a result, the degradation compound ratios were not the same in the glucose and SOME-amended channels. The outlet MC in the SOME and CT-fed channels depended on the residence time of the inlet CT, unlike the glucose-fed channel, where the concentrations of MC were similar irrespective of the time of a month. Most of the degradation process took place in the initial portion of the SOME-fed channel, due to sorption of SOME to soil organic matter. This study proved that the supplements glucose and SOME are effective substrates that can be added to CT-contaminated groundwater to achieve complete degradation of CT.

Acknowledgements

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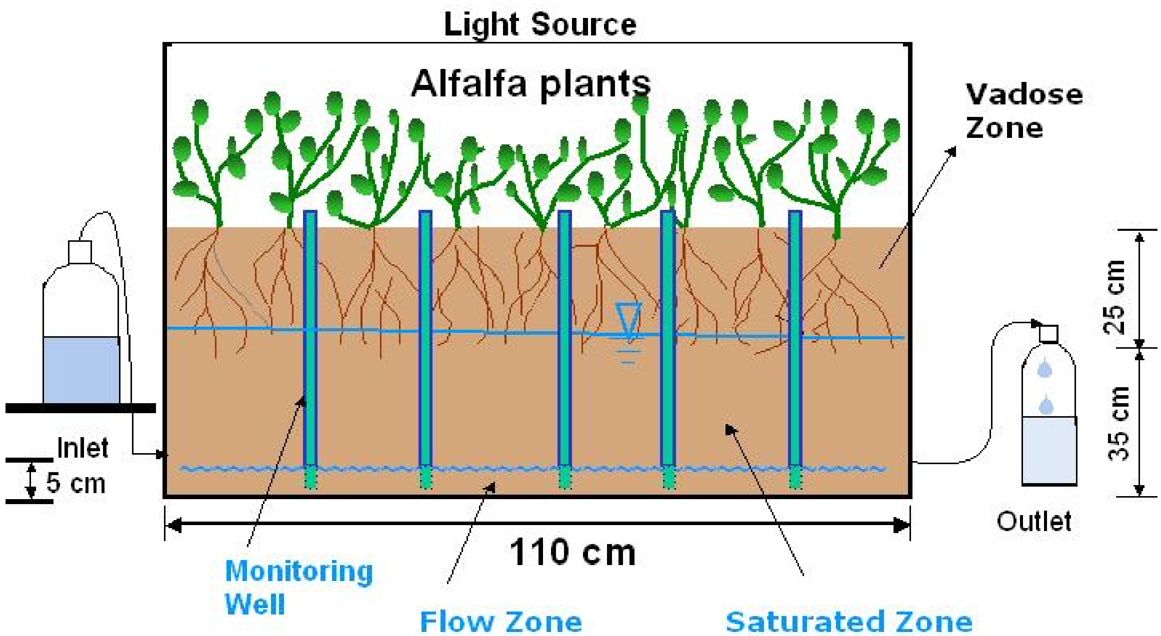

Figure 1. Schematic and cross-section of a channel in the six-channel System.

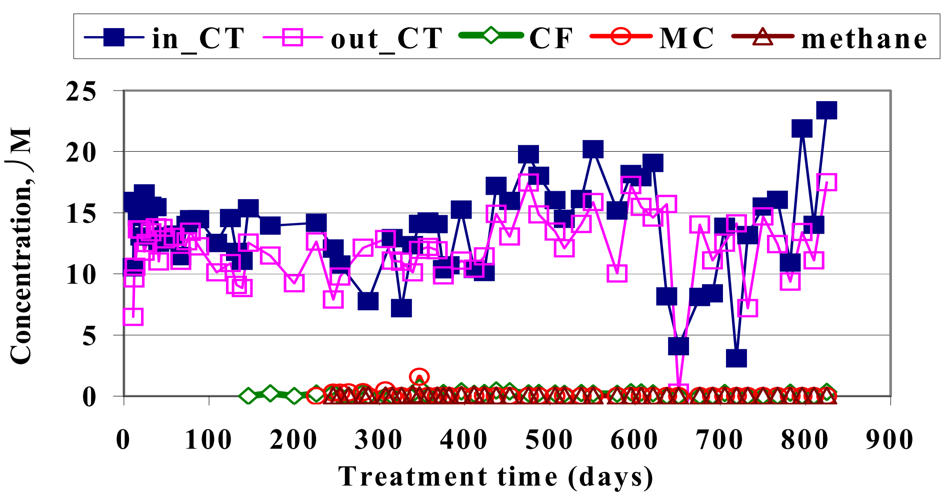

Figure 2. Inlet CT and outlet CT, CF, MC, and methane concentrations for channel 4 (control). Water samples taken on indicated days after beginning (March 12, 2004) exposure.

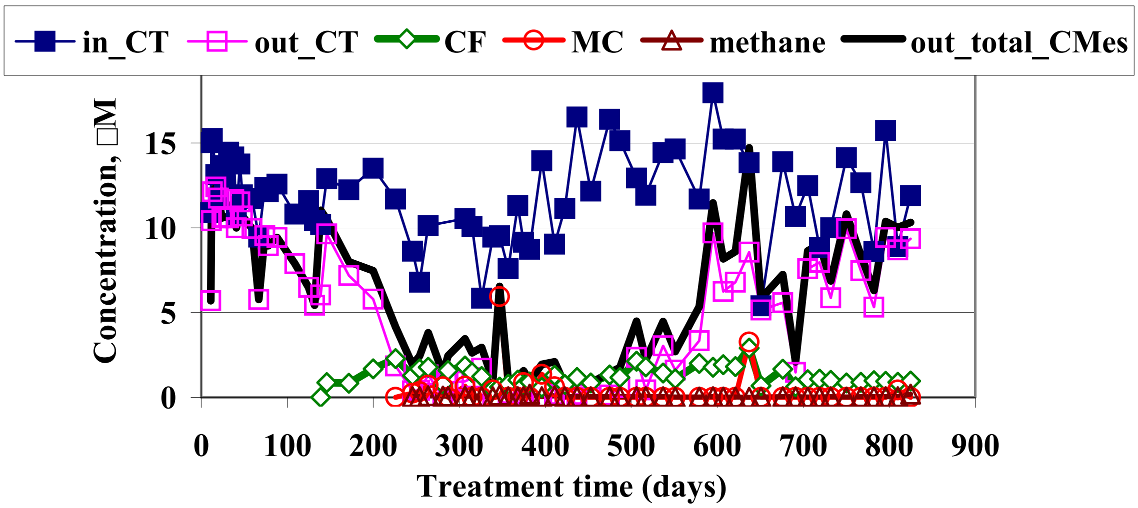

Figure 3. Inlet CT and outlet CT, CF, MC & methane concentrations for channel 5. Water samples taken on indicated days after beginning (March 12, 2004) exposure. Glucose solution added on day 110, 151, 173, 203 and 236; corn starch on days 266, 299 & 328.

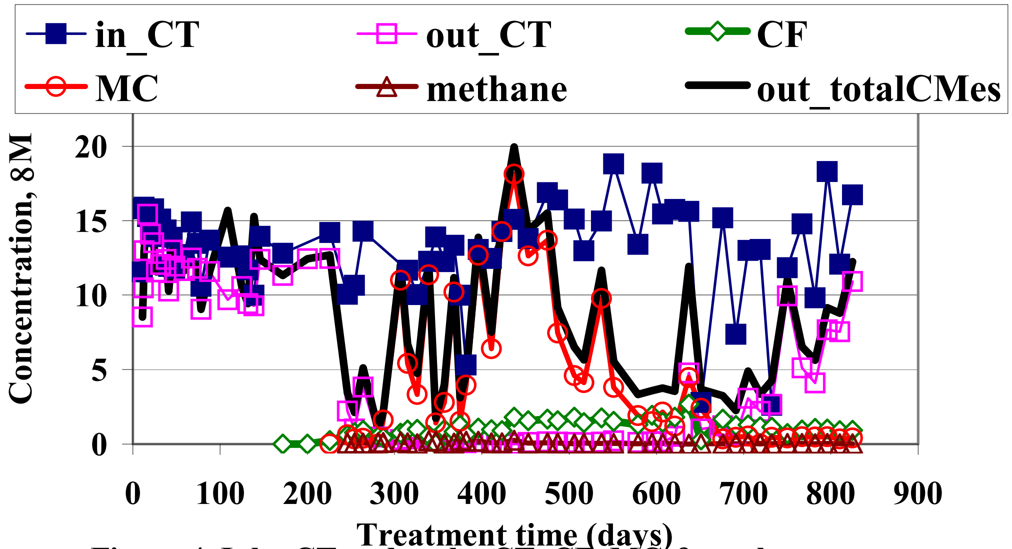

Figure 4. Inlet CT and outlet CT, CF, MC & methane concentrations for channel 6. Water samples taken on indicated days after beginning (March 12, 2004) exposure. Soy Oil Esters added on days 203, 236, 266, 299, 328, 359, 387, 415 & 445 (well 3).

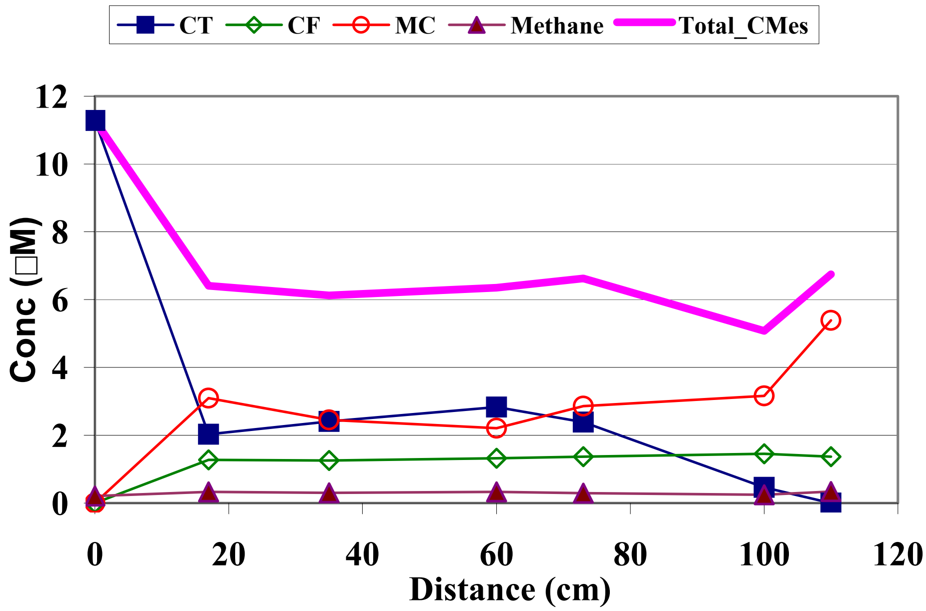

Figure 5. CT and degradation compounds with distance for ch6; day 438, 5/24/05. Soy Oil Methyl Esters (SOME) added on days 203, 236, 266, 299, 328, 359, 387, 415.

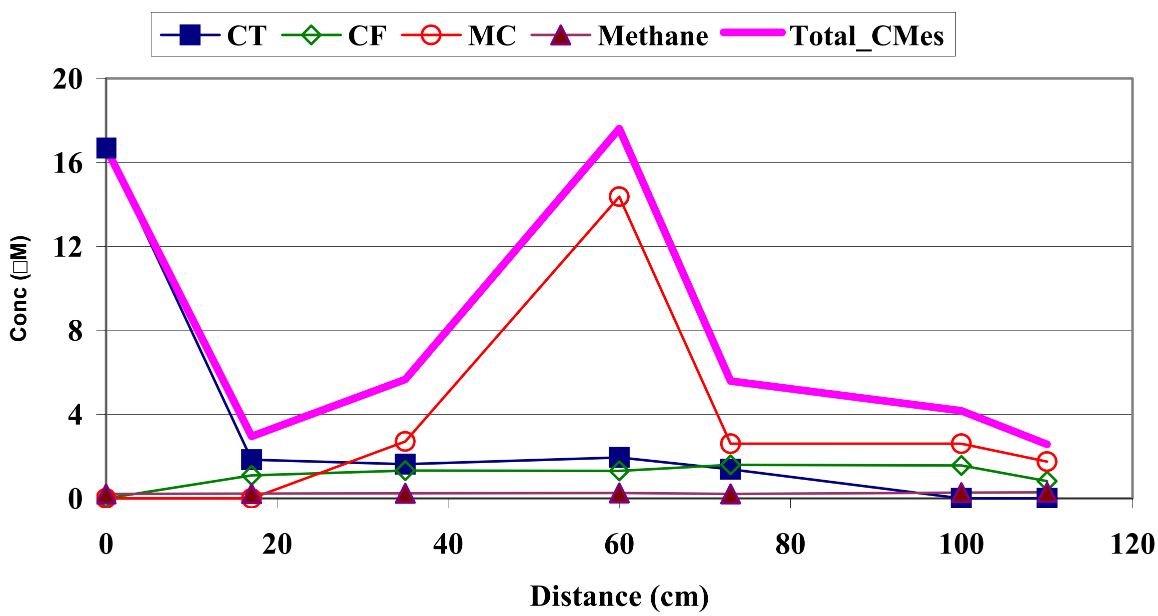

Figure 6. CT and degradation compounds with distance for ch6; day 495, 7/21/05. Soy Oil Methyl Esters (SOME) added on days 203, 236, 266, 299, 328, 359, 387, 415 & 445 (well 3).

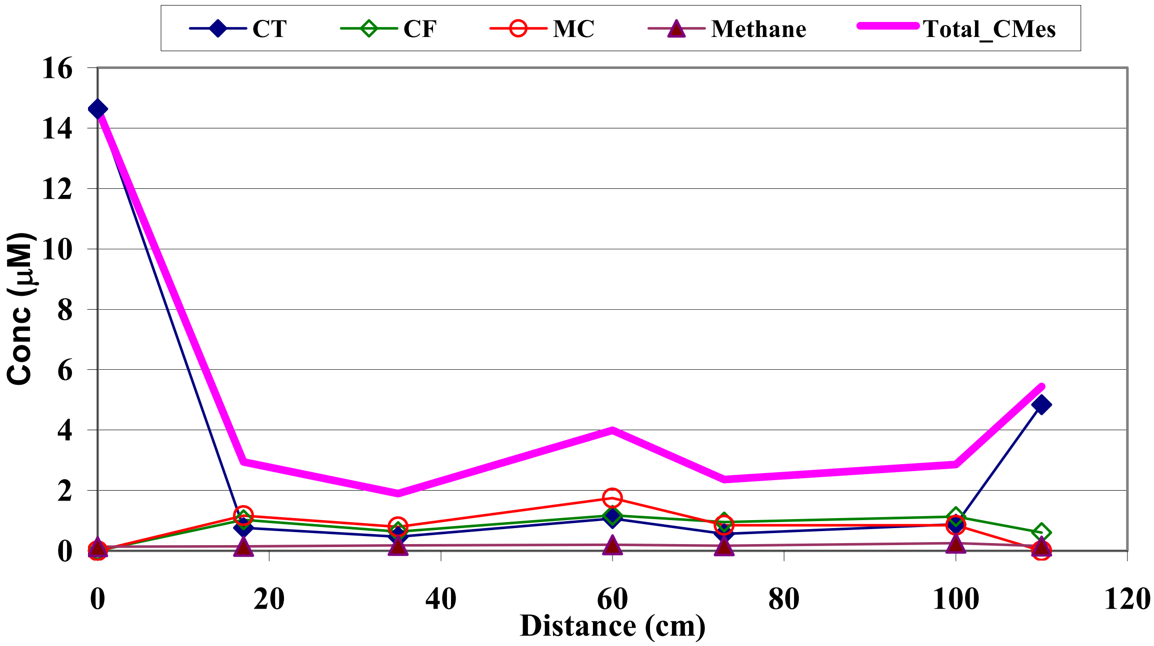

Figure 7. CT and degradation compounds with distance for ch6; day 741, 3/22/06. Soy Oil Methyl Esters (SOME) added on days 203, 236, 266, 299, 328, 359, 387, 415 & 445 (well 3).

APPLICATION OF NANOTECHNOLOGY TO AGRICULTURAL AIR QUALITY

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Abstract

There is a growing need for air that is free of pathogenic organisms and volatile organic compounds (VOCs) in the field of agriculture. In confined-animal feeding operations (CAFOs) infectious agents can enter with the air needed for ventilation. In order to prevent development and spread of diseases in animals contained in the area, there is a need to maintain acceptable concentrations of VOCs and microbial populations throughout the whole animal-raising facility. Food processing facilities and veterinary hospitals are additional places wherein air quality should be controlled. Similarly, maintaining good air in botanical research facilities and greenhouses is also important in addressing gaseous by-products they emit and plant-disease causing microbes that can infect the plants. Indeed, there are opportunities to make use of ultraviolet light and nanoscale destructive sorbents and photocatalysts such as titanium dioxide (TiO_2) in agricultural applications. This paper reviews the science, engineering, and current applications with an emphasis on agricultural applications.

Key words: nanotechnology, pathogens, photocatalytic oxidation, titanium dioxide, volatile organic compounds.

Introduction

Maintaining air quality in agricultural, food processing, and storage facilities is vital since workers are confronted with a variety of airborne occupational hazards. Diseases caused by pathogenic agents can spread among animals in animal facilities (Kowalski et al., 2002) or even infect workers through respiration of contaminated air or through direct contact. Foods being processed in food processing plants can be contaminated by pathogens dispersed in air. Kowalski et al. (2002) and Kowalski (2006) have presented several air quality control methods for the indoor environment in animal facilities. These include source control; purging of building air; and air treatment techniques such as filtration, ultraviolet germicidal irradiation (UVGI), and adsorption. Various disinfection methods have also been used (Kowalski, 2006). Microorganisms, however, have evolved defense and repair mechanisms in response to some of these methods (Blake et al., 1999). There is a need to develop new, effective, and practical ways to control pathogens.

One of the most promising technologies for indoor air is photocatalytic oxidation (PCO) with TiO_2 (Maness et al., 1999). Most of the previous studies, however, have dealt with volatile organic compounds (VOCs) and biological contaminants in aqueous solutions. Several studies have evaluated the effectiveness of UVGI against viruses, bacteria, and fungi, but most of these were done in water or on surfaces (Kowalski and Bahnfleth, 2004). Because PCO technology is a promising and effective method of disinfecting air (de Lasa et al., 2005), several studies are ongoing to expand its application, improve its efficiency to target organisms, optimize the process (e.g., modifying the photocatalyst TiO_2, using different configurations), and explore its potential for commercialization.

This paper reviews published information on PCO using TiO_2 as well as the air quality in animal and food processing facilities. This review includes research on underlying principles behind photocatalysis, its killing and oxidizing mechanisms, its advantages, and current application.

Air Quality in Agricultural, Food Processing, and Storage Facilities

Animal facilities pose risks of diseases from farm animals; allergies that may be caused by allergens from animal dander, animal feeds, or farm produce; health threats from mold and actinomycetes, as well as inhalation of harmful gases that can emanate from animals, mold, bacteria, waste, or sewage (Kowalski et al., 2002; Table 1). Poultry and swine houses are generally known to have large concentrations of airborne particles and microorganisms. In general, the microbial load in the air of poultry processing plants and meat processing plants is primarily from activities of live animals and birds before slaughtering. In the same way, slaughterhouses are prone to microbial airborne contamination. Organisms such as actinomycetes are also common in agriculture, thrive on materials like moldy hay, and promote diseases like farmer's lung (Kowalski, 2006). Some strains of these pathogenic agents not only can be transmitted between animals, but also from man to animals and vice versa. Other compounds such as ammonia and hydrogen sulfide can be produced from animal manures and in facilities rearing animals (ASHRAE, 1995; Kowalski, 2006). Likewise, food processing plants are faced with airborne pathogens and allergens of microbial or animal origin that may contaminate foods being processed (Kowalski, 2006; Table 2). Airborne aflatoxins can be generated in rice and maize processing plants (Kowalski, 2006).

Table 1. **Typical concentrations of airborne contaminants in animal houses** *(Kowalski et al., 2002).*

Contaminant	Average Concentration	*Location/condition*
Bacteria	237,000 cfu/m^3	Swine house
Bacteria	478,000 cfu/m^3	Poultry house
Bacteria	100,000 cfu/m^3 7,000,000 cfu/m^3	Swine houses Poultry houses
Gram-negative bacteria	88,000 cfu/m^3 41,000 cfu/m^3	Swine houses Poultry houses
Fungi	300 cfu/m^3 500 cfu/m^3	Swine houses Poultry houses
Dust particles	24,400,000 particles/ m^3	Swine house

Table 2. Typical bioaerosol levels in food processing facilities *(Kowalski, 2006)*.

Organism	Concentration (cfu/m^3)	Facility or area
Bacteria		
Enterrobacteriaceae	72-78	Poultry processing
E.coli	78	Poultry processing
	1,100-1,800	Slaughterhouses
Mainly Staphylococcus From fecal matter	400,000-4,000,000	Slaughterhouses
Staphylococcus	50,000	Poultry processing
	0-8,000	Poultry processing
Fungi	500-4,000	Slaughterhouses

Photocatalytic Oxidation

Photocatalytic oxidation (PCO), or heterogeneous photocatalysis, occurs when a semiconductor photocatalyst such as TiO_2, with band gap energy of 3.2 eV, is irradiated with photons of wavelength less than 385 nm (Indoor Environment Center, 2006). An electron is then promoted from the valence band to the conduction band after the band gap is exceeded. As a consequence, very potent, but short-lived oxidants such as hydroxyl radicals ($^\bullet OH$) and super oxide ions (O_2^-) are generated (Figure 1) (Frazer, 2001; Jacoby et al., 1996; Indoor Environment Center, 2006). Hydroxyl radicals are highly reactive (Blake et al., 1999) and non-selective oxidizers that can attack organic materials, including those that make up living cells. They break the cell wall and outer membrane, resulting in leakage of cell contents and cell damage, and eventual cell death. Superoxide ions, on the other hand, are longer lived, but cannot penetrate the cell membrane because of their negative charge. In general, both $^\bullet OH$ and O_2^- can oxidize various organic substances and biological contaminants, primarily converting them to CO_2 and H_2O.

Several steps are involved in photochemical mechanisms in solid semiconductors. These steps are described in detail in de Lasa et al. (2005) and Tompkins et al. (2005), and presented briefly herein. First**,** the light energy, h_v, greater than band gap energy, E_g, strikes the surface of the catalyst and excites an electron from valence band to conduction band. A valence-band hole, h_{vb}^{+}, is created, which migrates to the surface and initiates a reduction reaction. The conduction-band electron, e_{CB}^{-}, that successfully migrates to the surface also initiates a reduction reaction. The valence-band hole and conduction-band electron can recombine in the bulk material and on the surface. Tompkins et al. (2005) proposed a possible PCO pathway:

$$TiO_2 \xrightarrow{hv} TiO_2^{*}(e^{-}_{CB} + h^{+}_{VB}) \qquad (1)$$

$$TiO_2^{*}(e^{-}_{CB} + h^{+}_{VB}) \xrightarrow{recombination} TiO_2 + \text{heat} \qquad (2)$$

$$H_2O_{ads} \longrightarrow OH^{-}_{ads} + H^{+}_{ads} \qquad (3)$$

$$h^{+}_{VB} + OH^{-}_{ads} \longrightarrow {}^{\bullet}OH \qquad (4)$$

→ production of hydroxyl radicals

$$e^{-}_{CB} + O_2 \longrightarrow O_2^{-} \qquad (5)$$

→ production of super-oxide ions

$$^{\bullet}OH + \textit{Organic Reactants} + O_2 \longrightarrow \textit{Products } (CO_2, H_2O, \textit{etc}) \qquad (6)$$

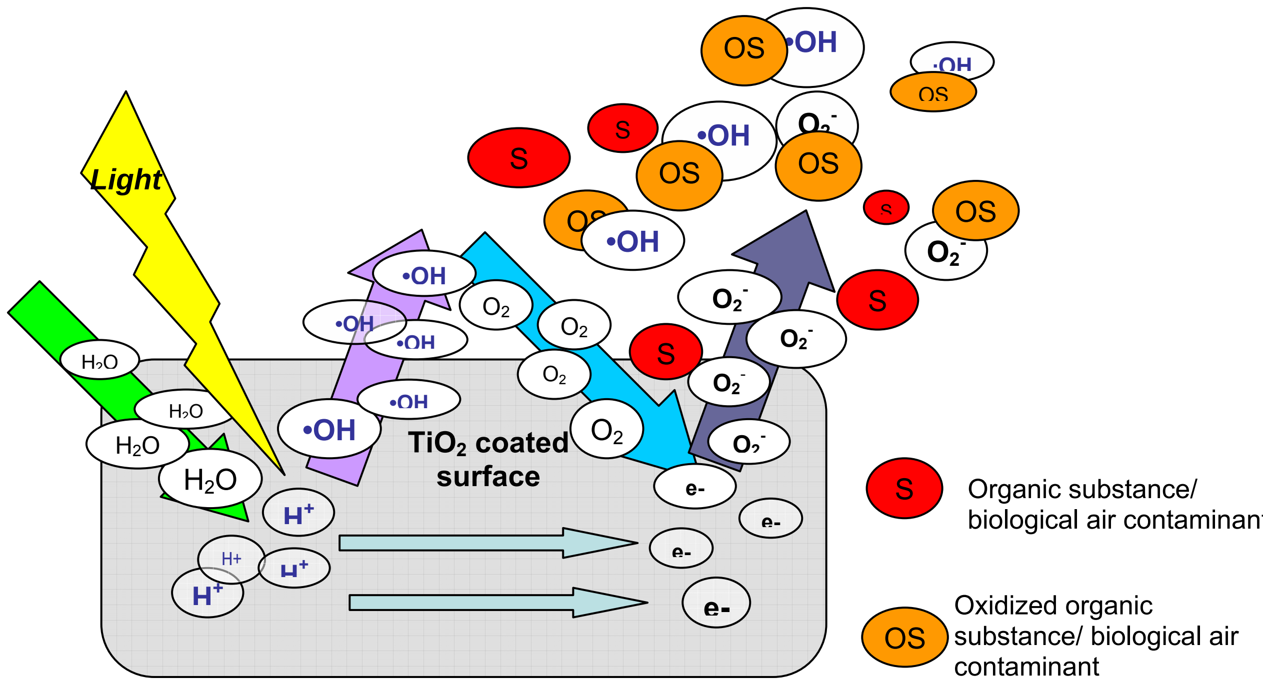

Figure 1. Schematic diagram of photocatalysis. As shown in equations (3) and (4), the hole in the valence band can react with water (H_2O) or hydroxide ions to produce hydroxyl radicals ($^{\bullet}OH$). Equation (5) shows how the electron in the conduction band can reduce oxygen (O_2) to produce superoxide ions (O_2^-). [Adapted from No Odor, Inc, 2006]

Characteristics of PCO

Photocatalytic oxidation is simple, relatively new, and a promising technology for air cleaning and disinfection. It is known to destroy even low-level pollutants in air. Near-UV light alone has been demonstrated to kill cells and microorganisms by damaging their cell walls and DNA. Its bactericidal activity is more intensified by using TiO_2 as the photocatalyst. Photocatalytic oxidation units are modular and can be scaled to suit a wide variety of indoor air quality applications. Because it cleans indoor air, it can reduce the amount of ventilation air exchange needed.

The most suitable photocatalysts are the metal oxide semiconductors, because of their photocorrosion resistance and their wide band gap energies. In PCO, factors that affect photocatalyst activity include structure of the photocatalyst, particle size, surface properties, preparation, spectral activation, and resistance to mechanical stresses. Titanium dioxide is considered the most active and most stable photocatalyst; it does not photo-corrode, is not very expensive, has good thermal stability, and is chemically and biologically inert and non-toxic. It can be prepared from ilmenite and rutile in two crystalline forms: anatase and rutile, the first having a crystalline form that gives superior activity. Different microorganisms, however, respond differently to TiO_2 photocatalyst. This is due to their structural differences and complexity (Huang et al., 2000). Most work has been done using the P_{25} form of TiO_2 produced by Degussa Chemical Company (Germany). To increase its photocatalytic power, researchers and other manufacturers have been continuously modifying its structure. This includes changing its size, or using another manufacturing method to increase its surface area, or doping it with other metals, metal ions and mixed-metal oxides.

First-order reaction kinetics has been proposed to describe the bactericidal reaction of the TiO_2 photocatalyst (Huang et al., 2000; Pal et al., 2005). Tompkins et al. (2005) also used this kinetic model and indicated that the Langmuir-Hinshelwood rate expression can provide a very good approximation of the overall reaction kinetics in as much as the process involves a reactant adsorbing on the surface of the catalyst. The 3.2-eV band gap of TiO_2 matches a wide variety of available artificial light sources. Evidence shows that TiO_2 photocatalytic reaction results in continued bactericidal activity, even after the UV illumination terminates (Huang et al., 2000).

Much work has been directed toward modifying TiO_2 and testing other semiconductors for process efficiency, and to improve overlap of the absorption spectrum of the photocatalyst with the solar spectrum. One of the major breakthroughs in the field of PCO is the emergence and application of nanotechnology. Nanostructured TiO_2 is expected to greatly enhance photocatalytic activity because it provides increased surface area for adsorption and reaction of the targeted organic substances on the catalyst. Smaller particles would also have a greater tendency to go inside the microorganisms and produce quicker intracellular damage (Huang et al., 2000). Furthermore, nanostructured TiO_2 promotes other effects associated with optical properties and size quantization.

Photocatalytic oxidation equipment can be operated at room temperature and with negligible pressure drop; it may be integrated into new and existing heating, ventilation, and air-conditioning systems. It reduces the absolute toxicity of the treated air stream, rather than merely moving it into another phase and concentrating the contaminant. It has low power consumption, potential long service, low maintenance requirements, and potentially can provide stability, if properly designed (Indoor Environment Center, 2006).

PCO and Bioaerosols

Photocatalytic oxidation inactivates and destroys airborne pathogenic organisms such as bacteria, fungi, viruses, as well as their spores. Studies have shown that PCO is more effective than UVGI in killing microorganisms (Figures 2 and 3). Other studies have also revealed that sensitivity of microorganisms to TiO_2 photocatalysis is likely in the following order: virus > bacterial cells > bacterial spores (Huang et al., 2000). Matsunaga et al. (1985) reported that the extent of killing was inversely proportional to the thickness of the cell wall.

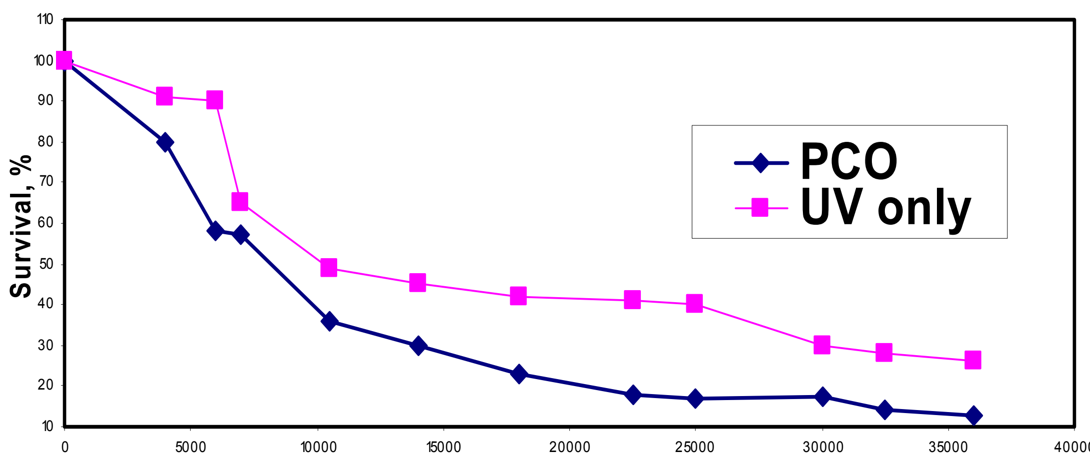

Figure 2. Survival rate of Serratia marcescens in a recirculation sytem of PCO compared with UV disinfection alone (Kowalski, 2006; Goswami et al., 1997).

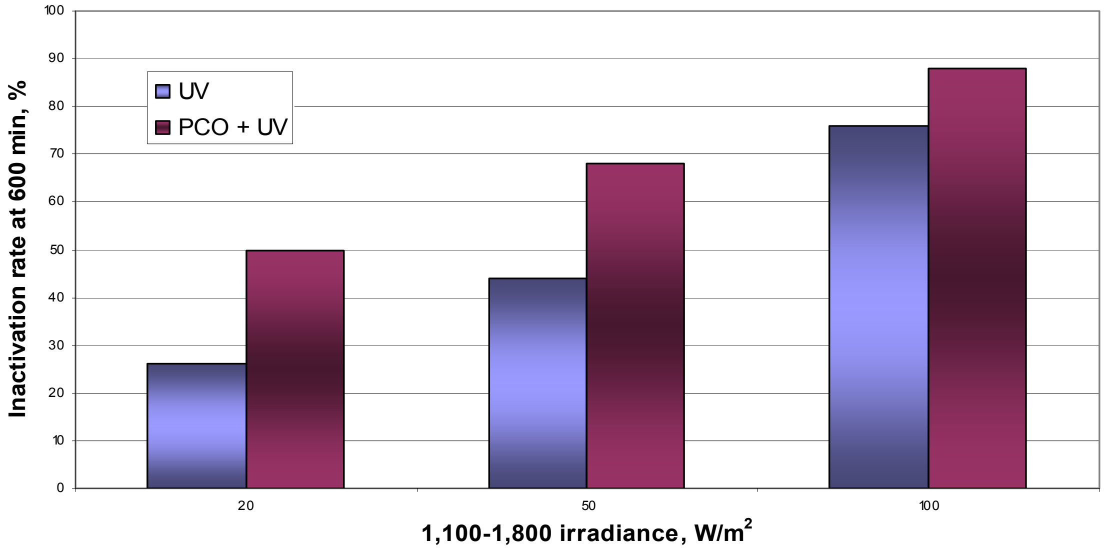

Figure 3. PCO inactivation rates vs. UV inactivation rates of *Serrastia marcescens* after 600 min in reactor; higher UV irradiance increases the photocatalytic effect (adapted from Kowalski, 2006; Goswami et al., 1997).

Potential Applications of PCO

PCO has potential in maintaining indoor air quality in animal houses and laboratory research facilities. It may also be effective in preventing contamination and microbial spoilage, as well as in the decomposition of harmful products in food processing and packaging plants (e.g., food and dairy plants). TiO_2 photocatalytic technology may be useful in fresh fruit and vegetable post-harvest storage by decomposing ethylene gas, a plant hormone that can induce fruit ripening and undesirable reaction like development of bitter flavors, loss of chlorophyll (yellowing of green leafy vegetables), and increased susceptibility to disease (Maneerat et al., 2003; Table 3).

Table 3. Percent decomposition of ethylene by TiO_2 photocatalytic reaction at different temperature and atmospheric conditions (Maneerat et al., 2003).

C_2H_4 (ppm)	TiO_2 Photocatalyst	Temp (ºC)	RH (%)	Atmosphere	Irradiation (24 h)	Decomposition (%)*
20.4	No	25	96	Air	Yes	6.2 a
19.8	Yes	25	95 - 96	Air	No	6.3 a
20.6	Yes	25	95 - 96	Air	Yes	99.3 b
208.8	Yes	15	96	Air	Yes	95.8 c
19.6	Yes	5	100	Air	Yes	92.0 d
21.2	Yes	25	96	5% to 10% O2	Yes	99.0 b
20.4	Yes	25	96	1% to 5% CO_2 in air	Yes	98.7 b

[*] Values followed by the same letter are not significantly different ($p<0.05$) according to Duncan's multipl-range test.

Advantages of PCO

PCO can remove both biological and chemical agents. It reduces absolute toxicity of the treated air stream rather than merely transforming it into another phase and concentrating the contaminant. The process can be operated at room temperature and with negligible pressure drop; it may be also integrated into new and existing heating, ventilation, and air-conditioning systems. If properly designed, PCO units can feature low power consumption, potential long service, and low maintenance requirements. Ozone that can be produced during PCO operation and other UV systems in the laboratory animal environment is advantageous due to its deodorizing power. Another advantage of PCO is that the UV sterilizing system eliminates hazards and waste disposal issues associated with chemical sterilization techniques.

Configurations and Reactor Designs

Typical and basic arrangement of a PCO unit as described by Kowalski (2003) is shown in Figure 4.

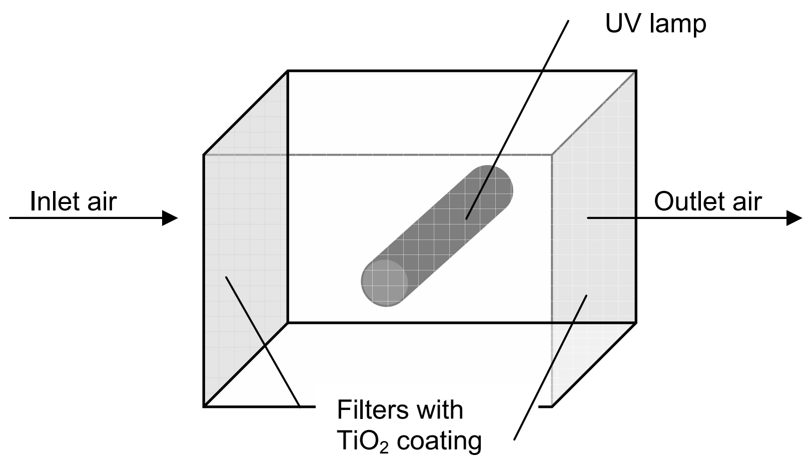

Figure 4. Possible arrangement for UV lamp and TiO_2 photocatalyst (Kowalski, 2003).

Other PCO reactor configurations and designs have been explored. These include fixed-supported powder layer; annular-packed bed; fluidized photocatalyst bed; use of honeycomb monolith as TiO_2 support; packed-bed design; fiber optic-based reactor; immobilized photocatalyst on fiberglass; solid glass beads; hollow, coiled glass tubes; pillared clays and zeolites; and a photo-CREC air unit with venturi, developed by Chemical Reactor Centre (CREC) of the University of Western Ontario. Various researchers (de Lasa et al., 2005; Ibrahim and de Lasa, 2000; Tompkins et al., 2005) have described the various configurations and designs just mentioned, including their advantages. Ibrahim and de Lasa (2000) assessed the photocatalytic conversion of the model pollutant (toluene) in a photo-CREC-air reactor under certain experimental conditions. They claimed that the system displays high energy efficiency and achieves total pollutant mineralization. In the unit evaluated, TiO_2 was supported on a filter mesh with good contacting of near UV light, TiO_2, and air. Initial photodegradation rates of toluene at 100ºC in the photo-CREC-air were 0.005 to 0.05 μmole/gcat.s. Apparent quantum yields were promising, i.e., greater than 100% and as high as 450% in many instances (Ibrahim and de Lasa, 2000).

Similar to other heterogeneous chemical reactions, catalyst supports in PCO are used to maximize active surface area. Catalysts can be fixed (anchored) on supports by means of physical surface forces or chemical bonds. Typical supports for PCO photocatalysts include activated carbon, fiber optic cables, fiberglass, glass rings, glass beads, glass wool, thin films, membranes, quartz sand, zeolites, silica, stainless steel, and polymers (Tompkins et al., 2005; de Lasa et al., 2005).

Jacoby et al. (1996) have used an annular geometry in the investigation of heterogeneous photocatalysis for control of VOCs in air. Likewise, Xu et al. (2005) evaluated the efficacy of an upper-room air UVGI system for the inactivation of airborne bacteria. In this configuration, the light source irradiates the upper part of the room while minimizing radiation exposure to persons in the lower part of the room.

Designs were tested, considering as performance qualifiers the levels of photoconversion of various classes of pollutants at different concentrations, temperatures, relative humidity, pressures, space times, and irradiation times (de Lasa et al., 2005).

Considerations for Design and Commercialization of PCO Systems

Although PCO has a lot of advantages, there are still technical barriers in the widespread application of this technology (CAE News, 2003). In designing commercial PCO units, several important factors must be considered. One is the type of microorganisms or compounds to be treated. Different microorganisms have different physico-chemical characteristics and, therefore, may respond to specific stimuli differently (Huang et al., 2000). For instance, Kowalski (2003, 2006) presented a table of different microorganisms categorized under biological weapon agents, which indicates their characteristics, as well as their different response or susceptibility to UVGI (with wavelength of about <254 nm), through the UVGI rate constants.

Reactor configuration, or the design of reactor geometry with respect to the irradiation source and catalyst locations, should be carefully investigated. Selection of radiation sources should consider output power, light intensity, source efficiency, spectral distribution, shape, dimensions, maintenance, and operating requirements (warm-up and cooling periods). Design of reactor irradiation devices should consider mirrors, reflectors, and windows, including construction materials, shape, dimensions, and cleaning procedures.

Controlling process variables, such as oxygen concentration, residence time, light illumination, properties of catalytic coating (photocatalyst), air movement pattern and velocity, and other conditions, are important components for the design of an effective PCO system and for optimization of the process.

Technical issues need to be considered in operating PCO systems. One of them is the need for a stable catalyst—its life, fouling, poisoning, and deactivation. Titanium dioxide is the most commonly used photocatalyst because of its stability and activity, but its band gap energy is too high for use with solar radiation (Zeltner and Tompkins, 2005).

Other considerations are the reaction rate inhibition due to humidity, mass transport issues, products of incomplete oxidation, and inorganic contamination (Jacoby et al., 1996; Indoor Environment Center, 2006). For example, water vapor molecules compete with other feed-stream gases, especially reactant species and molecular oxygen, for sites on the photocatalyst surface. For some compounds, however, humidity has a positive effect.

In mass transport issues associated with flow systems, high flow rate may decrease residence time and favor low conversion. Intermediate or undesired by-products can be formed as a result of incomplete oxidation, and may even be more toxic than the microorganisms or organic compounds being treated. Inorganic contamination of dust and soil may also reduce the illumination.

Another constraint in the commercialization of PCO is the need for light of suitable intensity and power. The light source should give a relatively uniform distribution of light throughout the chamber to use the photocatalyst effectively (Zeltner and Tompkins, 2005). The reactor should be accessible enough for cleaning and/or replacement of both the light source and photocatalyst.

Use of UV light in PCO may produce ozone, which can make the air foggy. Furthermore, UV light is rarely available in ambient indoor air, so it is not advisable to depend on ambient light alone. Performance and costs must be compared to existing air-cleaning technology in the design and commercialization of PCO systems.

Research and Development Needs

PCO is still in the developmental stage; principles and performance are not yet well understood. Actual performance data on PCO systems are limited in the present. Kinetic data, most especially for microorganisms, are also not yet well established and fully available. Added to this is the lack of performance indicators that will enable the comparison of photoreactor performance on the basis of photochemical and thermodynamic principles (Yue, 1985; Serrano and de Lasa, 1997). At present, commercial and residential applications are still questionable. PCO may be comparatively expensive; the initial cost for obtaining the equipment is high. Although most cost studies have focused on VOCs and did not take into account the benefits of air disinfection, performance characteristics are expected to improve with further research and development (Kowalski, 2006).

Current PCO systems can be improved by exploring new configurations and better light sources. There is also a need to develop better photocatalysts such as hybrid or metal-doped photocatalysts that can limit by-product formation, enhance reaction rates, increase the rate of target specie adsorption onto the catalyst surface, and respond to different wavelengths including visible light. Use of PCO in a mixed (multi)-gas air stream and the formation of reaction by-products need to be investigated also. PCO systems that can treat relatively large gas flows in devices with low pressure drop, generating good photocatalyst irradiation and providing efficient reactant species-photocatalyst contact, must be developed. Most studies on use of PCO on viruses, bacteria, and fungi were done in water and on surfaces. As such, there is a need to assess the technology in air under realistic conditions of indoor air environment, especially with use of nanoscale TiO_2. Furthermore, reliable data, including kinetic data on the performance of PCO against these microorganisms, must be collected.

Summary

Photocatalytic oxidation is one of the most promising technologies that can be used for disinfecting air. It has potential applications in agricultural and food processing industries; however, it is still in its developmental stage and its performance is not yet fully understood. Moreover, kinetic data are still not well established and fully available, especially for treating microorganisms. Although insufficient data are available on the effectiveness of PCO systems against biological agents, PCO systems, combined with filters, are expected to operate against both microbial pathogens and chemical agents. Several configurations and designs have been developed, but, there is still need to improve current designs to achieve more effective systems that will be able to address current operational issues and that can be made available for commercialization purposes.

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