Effect of Organic Pest Management Practices on Apple Productivity and Apple Food Safety

H. Friedrich[1], K. Delate[1], P. Domoto[1], G. Nonnecke[1] and L. Wilson[2]

[1]Department of Horticulture, Iowa State University, Ames, Iowa, U.S.A.

[2]Department of Food Science and Human Nutrition, Iowa State University, Ames, Iowa, U.S.A.

Send proofs to Heather Friedrich, Iowa State University, 106 Horticulture Hall, Ames, IA, U.S.A, 50011; hjfried@iastate.edu; phone: 515-294-5116, fax: 515-294-0730.

ABSTRACT

Research was conducted in a certified organic apple (*Malus x domestica* Borkh.) orchard in 2000 to determine the effect of organic pest management techniques on pest control, apple yields and microbial populations on harvested apples. In Experiment I, apple colouring bags, sticky red spheres, kaolin particle film, kaolin particle film plus sticky red spheres, or colouring bags plus sticky red spheres were applied to Redfree, Jonafree, and Liberty apple trees in a split-plot design. Insects and diseases were sampled in the control and kaolin particle film treatments. Apple yields and insect damage ratings at harvest were determined for all treatments. There was a significant treatment x cultivar interaction related to insect damage on apples. Insect and disease damage ratings throughout the growing season and at harvest were lowest in Jonafree trees treated with kaolin particle film or colouring bags. There was no effect of treatment on beneficial insects during the growing season. Marketability was greatest in the Jonafree apples treated with colouring bags or kaolin particle film. In Experiment II, the effect of the organic management practices in Experiment I on the food safety of harvested organic apples was examined. Microbial populations on untreated apples and apples treated with kaolin particle film or colouring bags were enumerated post-harvest. No *E.coli* populations were observed on any apples. Low populations (225.0 ± 95.0 colony-forming units [CFU] apple^{-1}) of coliform bacteria were observed on unwashed control apples. Postharvest yeast and mould populations were greatest on unwashed apples treated with kaolin particle film and lowest on apples protected by colouring bags. When kaolin particle film-treated apples were washed prior to analysis, yeast and mould populations were reduced by 50%.

INTRODUCTION

The Organic Farming Research Foundation (OFRF) Biennial National Organic Farmers'
Survey reported 145 organic apple orchards on 1111 ha in the U.S. in 1997 (Walz, 1999).
Successful organic apple production has been documented in Western U.S. (Sweazy *et
al.*, 2000) using insect mating disruption and integrated pest management. Reganold *et
al.* (2001) also demonstrated organic apple production systems with improved profits,
soil quality, taste and texture compared with conventional apples in Washington state.
With the development of disease-resistant cultivars for apple scab (*Venturia inaequalis*
[Cooke]) management, organic apple production in the Midwest has expanded to
commercial operations.

Other fungal diseases, such as fire blight (*Erwinia amylovora),* sooty blotch
(*Gloeodes pomigena*) and flyspeck (*Zygophiala jamaicensis*), also affect Midwestern
apples, but insect pests present the greatest challenge to organic production. Codling
moth (*Cydia pomonella* [L.]), plum curculio (*Conotrachelus nenuphar* [Herbst]) and
apple maggot (*Rhagoletis pomonella* [Walsh]) are considered the most destructive pests
in humid apple-growing regions (Phillips, 1998). Integrated approaches, including
mechanical, cultural and biological control methods, are utilized in certified organic
apple systems. Techniques used to disrupt reproduction, such as pheromone confusant
technology and sticky red sphere traps, have proven useful in managing codling moth and
apple maggot pest populations, respectively (Swezey *et al.*, 2000). Habitats for beneficial
insects also help create a favourable ratio of beneficial insects to pests (Wratten &
Thomas, 1990). A labour-intensive method of shaking apple trees to physically dislodge

plum curculio was the most widely-used control method in organic orchards prior to the introduction of kaolin particle film in 1999 (Thomas, 2000).

Kaolin particle film has proven successful in the management of insect pests and some diseases (Puterka *et al.*, 2000; Thomas, 2000). Kaolin particle film consists of 95% kaolin clay that is suspended in water for application. Pests are controlled by visual repellency of the white film protectant and from irritating particles adhering to insect integuments (Glenn *et al.*, 1999). Host 'masking' may also be involved when kaolin particle film thwarts insect recognition of the white-coated tree. Unruh *et al.* (2001) demonstrated the effectiveness of kaolin particle film against codling moth in apple and pear orchards. Apple maggot fly (Puterka *et al.*, 2000) and plum curculio (Puterka *et al.*, 2000; Thomas, 2000) were also controlled with kaolin particle film. Disease suppressiveness against flyspeck and sooty blotch was obtained with kaolin particle film (Thomas, 2000), due to the hydrophobic film created on the leaf or apple fruit (Glenn *et al.*, 1999).

Colouring bags aid colour formation in Fuji cultivars by inhibiting chlorophyll production (Kikuchi *et al.*, 1997), and can be used for plant protection. Because the bags protect the apples from insects and diseases at the beginning of the colonization period, fewer sprays are needed for pest management throughout the remainder of the season. Bagging fruit, however, is labour intensive and will increase costs of production (Kikuchi *et al.*, 1997).

Recently, concerns have been raised regarding potential microbial contamination of organic produce from raw or composted manure used for plant fertilization. Raw manure contaminated with pathogenic *Eschereshia coli* may contact crop plants or

agricultural packaging, if improperly handled (Jay, 2000). However, state and federal organic certification laws prohibit the application of raw manure to a horticultural crop 4 months prior to harvest (IDALS, 1999; USDA-AMS, 2000). Organic farmers also compost manure to temperatures of 60°C for at least 3 days to kill pathogenic organisms. Food grown according to the USDA organic standards must also comply with USDA food quality regulations.

Experiment I was conducted to determine the effect of commercially available organic pest management tools, including sticky red spheres, kaolin particle film and colouring bags, on insect damage from codling moth, plum curculio, apple maggot and incidental insect pests, such as leafminers, during the growing season and at harvest. In addition, these organic pest management treatments were evaluated for effects on apple diseases and yields in an organic apple orchard. Additive tactics of kaolin particle film plus sticky red spheres and colouring bags plus sticky red spheres were also evaluated for their effect on yields, diseases and insect damage on apples at harvest.

In order to determine the effect of these organic management practices on regulated, foodborne microbial populations, Experiment II examined whole, untreated apples and apples treated with colouring bags or kaolin particle film for coliform, *E. coli*, yeast and mould populations. Apples were tested as unwashed fruit directly from the orchard and after washing, simulating market preparation.

MATERIALS AND METHODS

Experiment I

A certified organic apple orchard in Runnells, Iowa, was selected as the research site for this experiment. Redfree, Jonafree and Liberty cultivars, on dwarf rootstock Malling 9 and B9, were planted in a three-tier trellis wire system on 23 April 1997. Disease-resistant apple cultivars selected for this orchard were consistent with local organic apple orchards. Commercial harvest of apples on dwarf rootstock typically occurs 3 years after planting, which coincided with the 2000 growing season.

Six rows of Redfree, seven rows of Jonafree and seven rows of Liberty trees were planted in a 0.4 ha orchard site. Rows were orientated north–south and trees were planted on 2.43 x 4.25 m centers with 18 trees planted in each row.

Double-layer colouring bags (Wilson Irrigation, Yakima, Washington), sticky red spheres (Gemplers, Beltsville, Wisconsin), kaolin particle film (Surround™, Englehard Corp., Iselin, NJ), kaolin particle film plus sticky red spheres and colouring bags plus sticky red spheres were applied to 18 trees of each cultivar in Spring 2000. Eighteen trees of each cultivar were designated as control trees and remained untreated throughout the experiment. For statistical purposes, each of the pest management tactics was evaluated as an individual treatment.

Colouring bags were placed on the apples on 6-12 June 2000, when apples were approximately 1.5-2.5 cm in diameter. The outer layer of the colouring bags was

removed 1 month before harvest and the inner layer was removed 2 weeks before harvest to allow for sufficient colour development (Bessin, 1998).

Plastic red spheres were coated with Tangle-trap™ (Grand Rapids, Michigan) and one sphere was placed on every third tree of each treated tree row on 6 June 2000. Apple maggot populations were monitored on the spheres during insect sampling periods.

Kaolin particle film was mixed according to the label rate of 28 kg ha^{-1} kaolin particle film to 935 l water and applied using a backpack CO_2 pressurized sprayer. The first application of kaolin particle film was applied approximately 3 weeks after petal fall, on 15 June 2000, with the final treatment applied 2 weeks before harvest of each cultivar. Final applications of kaolin particle film on Redfree trees occurred on 27 July, on Jonafree trees on 9 August, and on Liberty trees on 23 August 2000.

The colouring bag outer layer was removed on 13 July on Redfree fruit and the inner layer was removed on 27 July 2000 to correspond with the average 7-14 August harvest dates. Jonafree harvest normally occurs from 11-18 September; outer layers were removed 13 July, with the inner bag removed 9 August 2000. Because the range for Liberty harvest in 1998 and 2000 was 18-25 September, outer and inner layers were removed on 9 and 23 August 2000.

Three codling moth pheromone traps (Pheroncon[®], TRÉCÉ, Salinas, California) were positioned in the eastern, western and central quadrants of the orchard on 23 May 2000 to monitor codling moth flights. Traps were checked for codling moths during the sampling dates of 19 July, 3 August, and 16 August 2000. The codling moths in the traps were counted and removed to obtain an indication of the populations at that time.

Five randomly selected apples and five randomly selected leaves per five trees of each treatment in each cultivar were examined every 2 weeks from 21 June until 30 August. A disease rating was recorded for each apple and leaf showing disease symptoms. The disease rating consisted of the following scale: 1 = no symptoms of disease; 2 = 1-25% of leaf or apple showing disease symptoms; 3 = 26-50% of leaf or apple showing disease symptoms. Disease symptoms did not exceed 50% on any apples or leaves. Insect damage was recorded as number of 'strikes' from codling moth, plum curculio or apple maggot puncture wounds or ovipositional scars. Individual leafminer mines were also counted as 'strikes.' Beneficial insects included predacious lady beetles (predominantly *Coccinella septempunctata*), lacewings (*Chrysoperla carnea*) and syrphid (Diptera: Syrphidae) fly larvae. Beneficial insects were enumerated in order to determine the impact of kaolin particle film on these insects. Sampling occurred bi-weekly, on 21 June; 6 and 19 July; and 3, 16 and 30 August 2000.

Fresh weight of all mature apples and number of apples tree^{-1} from five Redfree and five Jonafree trees were recorded at harvest. Each apple from five trees was inspected for plum curculio and codling moth damage and the number of marketable fruit tree^{-1} was determined. Apples were determined marketable if apples were ≥ 8 cm in diameter and $\leq 10\%$ of the apple surface was blemished from insects or disease. Apples with insect feeding holes were considered unmarketable. This apple grading system was based on a system used by organic apple producers in the Midwest (R. Johnson, pers. commun., 1999). Organic apples are typically marketed through local channels where consumers are purchasing organic apples on a routine basis.

Variables were analysed as a split-plot model with cultivar as the whole-plot factor and pest management techniques as the sub-plot factor (SAS, 1996). Least significant differences (LSDs) at the 0.05 significance level were calculated.

Experiment II

Thirty-six mature apples of marketable quality were collected directly from trees in Experiment I. Four apples treated with colouring bags or kaolin particle film were collected and compared with apples from the untreated control rows of each cultivar. Apples were collected according to the following schedule: Redfree – 14 August, Jonafree – 30 August, and Liberty – 14 September 2000.

Each apple was placed into an individual sterile bag and transported in a cooler to Iowa State University. In the Food Science Department laboratory, individual, unwashed, whole apples were shaken in 100 ml of 0.1% peptone broth for 2 min. The solution was diluted to 10^0 and 10^{-1} for *E. coli* and coliform counts. Yeast and mould counts were taken on solutions diluted to 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} concentrations. Duplicate samples were used in this experiment.

Coliform and *E. coli* levels were enumerated using 3M Petrifilm *E. coli*/Coliform Count Plate™ (3M Microbiology Products, Minneapolis, Minnesota), following label directions. Incubation time and temperature followed AOAC Official Method 991.14 (AOAC, 1990). Plates were incubated at 35°C and observed for changes at 24 and 48 h. Interpretation of the petrifilm followed *E. coli*/Coliform petrifilm label directions and AOAC Official Method 991.14. Blue to red-blue colonies associated with gas were

counted as *E. coli* colonies. Red colonies associated with gas were counted as coliform colonies.

3M Petrifilm Yeast and Mold Count Plates™ (3M Microbiology Products, Minneapolis, Minnesota) were used to determine populations of yeast and moulds on whole apples. Label directions for Petrifilm Yeast and Mold Count Plates™ were followed for dispensing samples onto the petrifilm. The yeast and mould petrifilm plates were incubated at 20-25°C and examined at 3 and 5 days. Label directions were used for the enumeration of colonies. Yeast colonies were small and defined in shape, and coloured blue-green or off-white. Mould colonies were larger and more diffuse than yeast colonies, and of various colours. In the second part of this experiment, certified organic techniques were followed and apples were washed in running water (25°C) for 30 s. *E.coli*, coliform, yeast and mould populations were enumerated using methods described above. Data were analysed as a paired comparison using a t-test (SAS, 1996).

RESULTS AND DISCUSSION

Experiment I

The 2000 apple growing season was warmer and drier than normal, with precipitation limited to 34 mm in May, compared with a normal rainfall of 101 mm. The average high temperature for the month was 25˚C (Agricultural Meteorology, 2000), leading to an early apple harvest. The Redfree harvest occurred on 9 August 2000, which was within the early range of harvesting dates (Domoto *et al*., 1999). Jonafree apples were harvested on 25 August 2000, which corresponded to a harvest date 3 weeks earlier than average (Domoto *et al*., 1999). Due to dry weather and high winds, approximately 75% of

Liberty apples had prematurely fallen at the designated time of harvest. Therefore, in order to avoid confusing aerial insect damage with ground insect damage, harvest data for the Liberty cultivar were not collected. Liberty apples that remained on the trees were used in Experiment II, however.

Apple diseases were not considered significant problems in the 2000 season. Fire blight was observed on some trees within the orchard, but not within sampled trees. Flyspeck and sooty blotch were observed on Jonafree apples approximately 10 days before harvest. There was a significant effect of treatment and cultivar on disease on leaves during the growing season (Table 1). Jonafree leaves treated with kaolin particle film received lower disease ratings compared with the control. The highest disease ratings, however, were on kaolin-treated Redfree and Liberty leaves. Jonafree and Liberty apples treated with the kaolin particle film combinations had significantly lower disease ratings compared to the control. No significant effect on disease symptoms was observed in the Redfree cultivar.

Insect pest (leafminer, codling moth or plum curculio) damage was not significantly different among treatments or cultivars although beneficial insects varied significantly with cultivar during the growing season (Table 1). Insect pest damage on leaves of trees treated with kaolin particle film plus sticky red spheres was lower for Jonafree (0.80 ± 0.11 strikes) than for Redfree (1.59 ± 0.23) and Liberty (1.29 ± 0.14). Populations of beneficial insects were greater on Redfree and Liberty trees than on Jonafree. With less insect damage in the Jonafree trees, it is likely there were fewer prey available for predacious insects, leading to fewer natural enemies as well. Overall, there was no significant effect of kaolin particle film on beneficial insect populations.

11

There was a significant effect of treatment and cultivar on insect damage on apples, with a significant treatment x cultivar interaction (Table 1). Greater insect damage was observed on untreated Redfree (1.80 ± 0.21) and Jonafree (1.32 ± 0.15) apples compared with the apples treated with kaolin particle film over the entire season (1.17 ± 0.15 and 0.64 ± 0.08, respectively) (Table 1). Insect damage was similar on untreated and kaolin particle film-treated Liberty apples.

Because apple maggot flies or larvae were not detected during the 2000 season, the sticky red spheres should not have exerted any influence on total insect populations. When kaolin particle film and kaolin particle film plus sticky red spheres data were pooled in a separate analysis, however, the only change from the unpooled data analysis occurred in leaf disease ratings, where cultivar effects were highly significant (data not shown).

Apple productivity, in terms of number of apples tree^{-1}, was significantly affected by pest management technique (Table 2). There were significantly less apples tree^{-1} where colouring bags were used (18.80 ± 2.33) than with the control (48.0 ± 6.06) and all other treatments combined (43.80 ± 4.91). Redfree trees with colouring bags averaged 22.60 ± 3.72 fruits tree^{-1} compared with kaolin particle film-treated apple trees with 38.80 ± 6.64 fruits tree^{-1}. Manipulating the apples during bag attachment and when bags were removed from the apple on two occasions may have caused stem weakening and resulted in an increased number of dropped apples throughout the growing season.

Yields were not significantly affected by cultivar (Table 2) with the mean harvest weight 5.20 ± 0.40 kg tree^{-1}. Yields were affected by pest management technique,

however, with lowest yields in the Redfree trees with colouring bags (3.41 ± 0.55 kg tree^{-1}) and highest in kaolin particle film-treated Jonafree trees (8.02 ± 0.84 kg tree^{-1}).

There was a significant effect of treatment and cultivar on codling moth and plum curculio damage on harvested apples. The treatment x cultivar interaction was significant in the case of codling moth damage but not for plum curculio damage (Table 2). Kaolin particle film, kaolin particle film plus sticky red spheres and colouring bags plus sticky red spheres provided the greatest protection from plum curculio in Jonafree apples. There were 4.61 ± 1.86 strikes apple^{-1} for plum curculio on Jonafree apples treated with kaolin clay compared with 18.77 ± 9.11 strikes on untreated apples (Table 2). Overall, plum curculio damage was significantly less on Redfree apples than on Jonafree apples (Table 2). There were an average of 5.09 ± 2.94 strikes on untreated Redfree apples compared with 1.62 ± 1.00 strikes in the kaolin clay plus red spheres treatment (Table 2).

When the kaolin particle film data were pooled and compared with colouring bags and control apples, results for pest management treatment effects on plum curculio damage in Jonafree were not changed (data not shown). There were fewer apples damaged by plum curculio in the combined kaolin clay treatments than in the control. With lower plum curculio damage overall in Redfree, treatment effects were not significant in the pooled data comparison (data not shown).

Treatments, cultivars, and treatment x cultivar interactions significantly affected codling moth damage on apples at harvest in unpooled data (Table 2) and pooled data (data not shown). Colouring bags, colouring bags plus sticky red spheres, kaolin particle film and kaolin particle film plus sticky red spheres treatments reduced codling moth damage in Jonafree apples (Table 2). Codling moth damage was less in the control than

in the sticky red sphere treatments. As observed with plum curculio, codling moth damage was significantly less with Redfree than with Jonafree apples. The three codling moth pheromone traps indicated a codling moth flight around 19 July and another flight around 16 August 2000. The Redfree trees were harvested on 9 August, escaping the later flight of codling moths. This may explain the greater percentage of codling moth damage in the Jonafree apples (harvested 25 August) compared with Redfree apples. It is likely that there would be greater codling moth damage in Liberty apples because the expected Liberty harvest date of 25 September would have provided a longer exposure to codling moth populations.

Percentage of marketable fruit at harvest was affected by treatment and treatment x cultivar interactions (Table 2). The highest percentage of marketable fruit (98.00 ± 0.88%) was obtained in the colouring bags plus sticky red spheres treatments. Control apples had the lowest percentage of marketable fruit (64.49 ± 4.20%) (Table 2). In the pooled data comparisons, combined colouring bag treatments and combined kaolin clay treatments provided the greatest percentage of marketable fruits (88.5% and 83.2%, respectively) compared with 69.4% marketable fruit in the control rows (data not shown).

Experiment II

No coliform or *E. coli* colonies were observed on the control, colouring bagged or kaolin particle film-treated Redfree and Jonafree apples from Experiment I. One of four untreated control Liberty apples was found to contain coliform colonies (225.0 ± 95.0 CFU apple^{-1}).

Because there were visual similarities between the yeast and mould colonies on the Yeast and Mold Count Plate™, a total population count for yeast and moulds was recorded. There were significantly greater yeast and mould populations on Redfree, Jonafree and Liberty apples treated with kaolin particle film compared with colouring bags and the control apples (Figure 1). Yeast and mould populations were greater on Jonafree than on Redfree apples. The Jonafree apples in the kaolin particle film treatment had significantly higher microbial populations compared with the control and colouring bag treatments (Figure 1). Populations of yeast and mould were significantly less in Liberty apples in the colouring bag treatment compared with the control and kaolin particle film treatments (Figure 1). Populations of yeast and mould were significantly less in Liberty apples in the control and colouring bag treatments compared with the kaolin particle film treatment. Yeast and moulds averaged 75000 ± 12817 CFU apple^{-1} on apples treated with colouring bags compared with 313750 ± 30292 CFU apple^{-1} on particle film-treated apples.

The microbial levels found on organic apples in this experiment were comparable to the microbial levels of unwashed, whole, conventional apples in Iowa, in a study in the Food Science Department at Iowa State University (Cummins, 2001). The range of yeast and mould on the apples in the Iowa State study was 20000-12000000 CFU apple^{-1} and the range of coliform populations was 100-100000 CFU apple^{-1} (Cummins, 2001).

Washing produce before consumption will reduce foodborne pathogens and microbial populations associated with spoilage. When kaolin particle film-treated apples were washed with water, yeast and mould populations were reduced from 362143 to 190929 CFU $^{-1}$ apple (Figure 2).

The greatest differences in microbial populations, within a cultivar, were detected between colouring bags and kaolin particle film treatments. Colouring bags serve as a physical barrier around the apple, which mitigates colonization by insect, disease, or foodborne microbial organisms if established early in the season. Kaolin particle film also creates a physical barrier when applied early in the season and continued every 7 to 14 days. Any microorganisms that colonize apples between applications, however, may be 'trapped' between the layers of kaolin particle film and may be detected in postharvest microbial analysis. While washing is a common practice in apple-growing areas where particle film is applied, peeling of apple skin will eliminate the protective particle film and decrease microbial loads prior to cider-making or other processing.

In summary, selection of cultivar in an organic apple orchard appears to affect the level of insect damage during the growing season and plum curculio and codling moth damage ratings at harvest. Organic pest management treatments also significantly affected plum curculio and codling moth damage ratings at harvest. Cultivar x treatment interactions were significant for disease and insect damage during the growing season, codling moth damage ratings at harvest, and percentage of marketable fruit. As demonstrated by Glenn *et al*. (1999) and Puterka (2000), kaolin particle film was effective in protecting against insect damage on Redfree and Jonafree apples. There was no effect on yields in either the Redfree or Jonafree cultivars from the treatments applied in this experiment. Overall marketability was not improved by the treatments in the Redfree cultivar, but marketability was improved in the Jonafree apples. One explanation for this outcome could be related to the maturity dates of these cultivars. Since Redfree is an earlier maturing cultivar, apples would be exposed to fewer insects and disease

organisms over time, thus lowering overall pest damage ratings. In addition, the effectiveness of the kaolin particle film may not have been fully realized in the Redfree cultivar due to the late starting date of the applications. Overall marketability was greatest in the Jonafree cultivar where the colouring bags or kaolin particle film were used.

Based on the efficacy of kaolin particle film in managing insects and diseases in Experiment I, increased use is anticipated in organic apple orchards. With the requirement for a 5-$\log_{10}$ reduction of microbial populations with new Hazard Analysis Critical Control Point (HACCP) regulations by 2004 (FDA, 2001), it is expected that washing and peeling particle film-treated apples will be incorporated as best management practices for organic cider producers.

REFERENCES

Agricultural Meteorology (2000). *Precipitation and Temperature Statistics*. Department of Agronomy, Iowa State University; Ames, Iowa, U.S.A.

AOAC (Association of Official Analytical Chemists) (1990). Official Methods of

> Analysis of the Association of Official Analytical Chemists. 15th edn.

> Association of Official Analytical Chemists; Washington, D.C., U.S.A.

Bessin, R. (1998). Bagging Apples: Alternative Pest Management for Hobbyists.

> University of Kentucky; Lexington, Kentucky, U.S.A.

Cummins, A. (2001). A survey of Iowa apple cider: Microbial loads and producers'

> production practices. MS thesis. Department of Food Science and Human

> Nutrition. Iowa State University; Ames, Iowa, U.S.A.

Domoto, P., Gleason, M. & Zriba, N. (1999). Growth and fruiting characteristics of

> cultivars in the 1993 ISU disease resistant apple cultivars trial for 1998. *Annual*

> *Fruit/Vegetable Progress Report 1998*, pp. 53-55. FG 601, Iowa State

> University; Ames, Iowa, U.S.A.

Food and Drug Administration (FDA) (2001). FDA publishes final rule to increase safety

> of fruit and vegetable juices. FDA; Washington D.C. January 18 2001.

Glenn, D.M., Puterka, G.J., Vanderzwet, T., Byers, R.E. & Feldhake, C. (1999).

> Hydrophobic particle films: A new paradigm for suppression of arthropod pests

> and plant diseases. *Journal of Economic Entomology*, **92**,759–771.

IDALS (Iowa Department of Agriculture and Land Stewardship) (1999). *Iowa Organic*

> *Certification and Organic Standards*. IDALS; Des Moines, Iowa, U.S.A.

Jay, J. (2000). *Modern Food Microbiology*. 6th edn. Aspen Publishers; Gaithersburg,

> Maryland, U.S.A.

Kikuchi, T., Arakawa, O. & Norton, R.N. (1997). Improving skin of 'Fuji' apple in Japan.

> *Fruit Cultivars Journal*, **51**, 71-75.

Phillips, M. (1998). *The Apple Grower*. Chelsea Green Publishing Company; White

    River Junction, Vermont, U.S.A.

Puterka, G.J., Glenn, D.M., Sekutowski, D.G., Unruh, T.R. & Jones, S.K. (2000).

    Progress towards liquid formulations of particle films for insect and disease

    control in pear. *Environmental Entomology*, **29**, 329–339.

Reganold, J.P., Glover, J.D., Andrews, P.K. & Hinman, H.R. (2001). Sustainability of

    three apple production systems. *Nature*, **410**, 926-929.

SAS Institute (1996). *SAS/STAT User's Guide, ver. 6.12*. SAS Institute, Inc.; Cary, North

    Carolina, U.S.A.

Swezey, S.L., Vossen, P., Caprile, J. & Bentley, W. (2000). *Organic Apple Production*

    Manual. Publication 3403. University of California; Santa Cruz, California,

    U.S.A.

Thomas, A. (2000). *Evaluation of Kaolin-Based Particle Film Coating on Insect and*

    Disease Suppression in Apples. Organic Farming Research Foundation (OFRF);

    Santa Cruz, California, U.S.A.

Unruh, T.A., Knight, A.L., Upton, J., Glenn, D.M. & Puterka, G.J. (2001). Particle films

    for suppression of the codling moth (Lepidoptera: Tortricidae) in apple and pear

    orchards. *Journal of Economic Entomology*, **93**, 737-743.

USDA-AMS (United States Department of Agriculture, Agriculture Marketing Service)

    (2000). National Organic Program. Final rule: 7 CFR Part 205. Available at:

    http://www.ams.usda.gov/nop.

Walz, E. (1999). *Final Results of the 3rd Biennial National Organic Farming Survey*.

    Organic Farming Research Foundation; Santa Cruz, California, U.S.A.

Wratten, S.D. & Thomas, M.B. (1990). Environmental manipulation for the

    encouragement of natural enemies of pests. In *Crop Protection in Organic and*

    Low Input Agriculture: Options for Reducing Agrochemical Usage. (R.J. Unwin,

    ed.), Vol. 45, pp. 87-92. British Crop Protection Council*;* Farnham, Surrey,

    England.

TABLE 1

Insect damage, beneficial insects and disease on Redfree, Jonafree and Liberty leaves and

apples during the growing season. Values are mean ± SE.

Treatment	Insect damage on leaves	Beneficial insects on leaves	Disease rating on leaves[1]	Insect damage on apples	Disease rating on apples[1]
Redfree					
Control	1.44 ± 0.26	0.25 ± 0.07	1.45 ± 0.07	1.80 ± 0.21	1.00 ± 0.00
Kaolin particle film	1.61 ± 0.23	0.35 ± 0.07	1.60 ± 0.06	1.17 ± 0.15	1.00 ± 0.00
Kaolin particle film plus sticky red spheres	1.59 ± 0.23	0.43 ± 0.10	1.48 ± 0.06	1.15 ± 0.15	1.00 ± 0.00
Jonafree					
Control	1.10 ± 0.13	0.15 ± 0.04	1.44 ± 0.05	1.32 ± 0.13	1.31 ± 0.05
Kaolin particle film	1.16 ± 0.12	0.15 ± 0.04	1.34 ± 0.05	0.64 ± 0.08	1.16 ± 0.04
Kaolin particle film plus sticky red spheres	0.80 ± 0.11	0.13 ± 0.04	1.44 ± 0.06	0.81 ± 0.11	1.15 ± 0.0

(continued)

TABLE 1 (continued)

Treatment	Insect damage on leaves	Beneficial insects on leaves	Disease rating on leaves [1]	Insect damage on apples	Disease rating on apples [1]
Liberty					
Control	1.49 ± 0.16	0.23 ± 0.05	1.32 ± 0.05	1.00 ± 0.12	1.16 ± 0.04
Kaolin particle film	1.48 ± 0.19	0.27 ± 0.06	1.53 ± 0.05	1.12 ± 0.13	1.05 ± 0.02
Kaolin particle film plus sticky red spheres	1.29 ± 0.14	0.22 ± 0.05	1.37 ± 0.05	$1.03 \pm .014$	1.01 ± 0.01
LSD $_{0.05}$ treatments within cultivar	n.s.	n.s	0.08	0.20	0.05
LSD $_{0.05}$ treatments between cultivars	n.s.	n.s.	0.08	0.19	0.05
Treatment x cultivar	n.s.	n.s.	*	*	*

[1] Mean disease incidence was rated visually on five leaves per treatment: 1 = no

symptoms of disease; 2 = 1–25% of

apple or leaf showing disease symptoms; 3 = 26–50% showing disease symptoms. No

apples or leaves had disease

symptoms above 50%. n.s. Nonsignificant; * significant at $p < 0.05$

TABLE 2

Redfree and Jonafree apple yields, insect incidence and marketable fruit at harvest. All

fruits from five trees per

treatment per cultivar (n = 60 trees) were measured. Liberty harvest data were not

recorded. Values are mean ± SE.

Treatment	Fresh weight (kg tree^{-1})	Apples tree^{-1}	Marketable fruit (%)	Plum curculio damage (%)	Codling moth damage (%)
Redfree					
Control	5.76 ± 1.50	37.20 ± 8.61	78.19 ± 3.89	5.09 ± 2.94	7.19 ± 1.50
Colouring bags	3.41 ± 0.55	22.60 ± 3.72	83.19 ± 6.60	3.79 ± 2.98	2.97 ± 1.82
Sticky red spheres	6.09 ± 1.22	47.40 ± 11.55	82.26 ± 6.90	7.48 ± 2.84	14.66 ± 8.82
Kaolin particle film	6.07 ± 0.67	38.80 ± 6.64	80.62 ± 9.92	4.44 ± 3.13	1.10 ± 0.74
Kaolin particle film plus sticky red spheres	5.64 ± 1.00	34.00 ± 6.57	82.80 ± 5.38	1.62 ± 1.00	1.62 ± 1.00
Colouring bags plus sticky red spheres	4.39 ± 0.39	27.60 ± 3.01	89.82 ± 3.18	1.33 ± 0.83	0.56 ± 0.56

(continued)

TABLE 2 (continued)

Treatment	Fresh weight (kg tree^{-1})	Apples tree^{-1}	Marketable fruit (%)	Plum curculio damage (%)	Codling moth damage (%)
Jonafree					
Control	7.91 ± 0.46	58.80 ± 5.76	64.49 ± 4.20	18.77 ± 9.11	19.80 ± 2.51
Colouring bags	7.43 ± 5.03	15.00 ± 1.84	83.89 ± 3.96	23.33 ± 14.53	3.33 ± 2.11
Sticky red spheres	7.27 ± 0.62	52.80 ± 4.60	52.65 ± 5.46	29.89 ± 4.50	33.75 ± 4.35
Kaolin particle film	8.02 ± 0.84	56.60 ± 10.19	88.28 ± 3.04	4.61 ± 1.86	1.65 ± 0.90
Kaolin particle film plus sticky red spheres	4.73 ± 0.85	33.20 ± 8.49	81.23 ± 2.02	4.70 ± 2.83	2.42 ± 0.77
Colouring bags plus sticky red spheres	5.86 ± 0.85	38.40 ± 5.80	98.00 ± 0.88	6.67 ± 2.47	0.00 ± 0.00
LSD $_{0.05}$ treatments within cultivar	n.s.	14.04	10.40	11.15	6.26
LSD $_{0.05}$ treatments between cultivars	1.94	n.s.	6.00	n.s.	3.61
Treatment x cultivar	n.s.	n.s.	*	n.s.	*

n.s. Nonsignificant; * significant at $p < 0.05$