4.2. METHANE AND NITROUS OXIDE EMISSIONS FROM AGRICULTURE

4.2.1 ADVANCED AGRICULTURAL SYSTEMS FOR N_2O EMISSION REDUCTION

Technology Description

No-tillage cropping system in irrigated agriculture to reduce Net global warming potential (A.D. Halvorson, USDA-ARS, Fort Collins, Colorado)

Low fertilizer nitrogen-use efficiency in agricultural systems is primarily caused by large nitrogen losses due to leaching and gaseous emissions (ammonia, nitrous oxide, nitric oxide, nitrogen). It is axiomatic then that most strategies that increase the efficiency use of fertilizer nitrogen will reduce emissions of N_2O and probably NO. In general, nitrogen oxide emissions from mineral and organic nitrogen can be decreased by management practices that optimize the crop's natural ability to compete with processes where plant-available nitrogen is lost from the soil-plant system, and/or by directly lowering the rate and duration of the loss processes. Strategies to increase the overall efficiency of nitrogen are therefore necessary to decrease nitrogen oxide emissions. Advanced agricultural systems are a group of technologies that can be applied to this goal. These systems enable a process of collecting and using increasingly detailed, site-specific information in conjunction with traditional farm-management tools, and applying the best available information to better manage individual farming operations. These systems conceptually provide for improved understanding, control, and manipulation of the soil/plant/atmosphere environment to match nutrient, water, pesticide, and other inputs for crop production demand, which will increase efficiency of nutrients and decrease gaseous and leaching losses. These systems provide an integrated capability to improve environmental quality while enhancing economic productivity by increasing energy efficiency, optimizing fertilizer and other chemical applications, and conserving soil and water resources. Most system concepts for reduction of GHG emissions are, however, theoretical and remain untested.

System Concepts

- Precision agriculture – global-positioning infrastructure and remote and *in situ* sensors for soil, crop, and microclimate characterization; this practice includes variable rate water, fertilizer, and pesticide application in space and time.
- Cropping system models, data and information analysis, and management tools.
- Control-release fertilizer and pesticide delivery to match crop demand and timing of pest infestation.
- Biological and chemical methods for manipulating soil microbial processes to increase efficiency of nutrient uptake, suppress N_2O emissions, and reduce leaching.
- Best-management practices to limit nitrogen gas emissions, soil erosion, and leaching.
- Soil-conservation practices utilizing buffers and conservation reserves.
- Recycling of livestock manure.
- Plant breeding to increase nutrient-use efficiency and decrease demand for pesticides and energy consumption.

Representative Technologies

- Global-positioning satellites and ground systems, satellite- and aircraft-based remote and *in situ* electrical, magnetic, optical, chemical, and biological sensors.
- Advanced artificial intelligence and information networking technologies; autonomous control and robotics systems; soil/ crop moisture, pest and microclimate responsive (smart) materials.
- Control-release fertilizers and pesticides.
- Nitrogen transformation inhibitors.
- Livestock waste delivery systems.
- Best-management practices.
- Genetically engineered plants that are resistant to herbicides or specific pests.

Technology Status/Applications

- Many first-generation precision agriculture technologies are available; in 1998, used on about 14% of farms.
- Information management and networking tools; rapid soil-characterization sensors; selected crop stress, yield, and quality sensors; and a systematic integration of all technologies for all major cropping systems are not yet at technical performance levels and require field testing.
- Strong understanding of soil microbiology and soil processes and relationships exist in the agriculture, energy, and university research community.
- Capability exists for the development of control-release materials and biological process inhibitors.
- Best-management practices are in place in many production sectors.

Current Research, Development, and Demonstration

RD&D Goals

- Precision agriculture technologies that improve production efficiencies and reduce energy consumption.
- Remote and field-deployed sensors/monitors and information-management systems for accurate, real-time monitoring and analysis of crops, soils, water, fertilizer, and agricultural chemicals use/efficiency to meet the fertilizer and energy reduction goals.
- Smart materials for prescription release utilized in major crops.
- Advanced fertilizers and technologies to improve fertilizer efficiency and reduce nitrogen inputs.
- Methods of manipulating soil microbial processes to increase efficiency of nitrogen use.
- Deployment of first-generation integrated system models, technology, and supporting education and extension infrastructure.
- Genetically designed major crop plants to utilize fertilizer more efficiently.
- First generation integrated system models, technology and supporting education and extension infrastructure need to be implemented, and research on using these techniques to improve management expanded.
- Full utilization of best-management practices.

RD&D Challenges

- Precision agriculture in general requires advances in rapid, low-cost, and accurate soil nutrient and physical property characterization; real-time crop water need characterization; real-time crop yield and quality characterization; real-time insect and pest infestation characterization; autonomous control systems; and integrated physiological model and massive data/information management systems. All of these require a full understanding of the spatial and temporal dynamics that occur within a field.
- Smart materials that will release chemicals based on soil and crop status depend on modest breakthroughs in materials technology.
- Improved understanding of specific soil microbial processes is required to support development of methods for manipulation and how manipulation impacts greenhouse gas emissions.
- Models that represent accurate understanding of plant physiology must be coupled with models that represent soil processes such as decomposition, nutrient cycling, gaseous diffusion, water flow, and storage to understand how ecosystems respond to environmental and management change.
- Detailed and simultaneous examination of biogeochemical reactions that occur in near-surface ground water is required to improve understanding of nutrient cycling, GHG emissions, and degradation of contaminants.
- Improved understanding of agro-ecosystem management on nitrogen cycling and GHG emissions.
- Development of plant varieties that increase nutrient use efficiency.
- Conduct direct basic and applied research effort on sensors, information sciences, materials, and microbial processes.
- Apply whole-systems engineering and integration to effectively develop and guide program formulation and implementation to include the concept of whole system net GHG emissions.

RD&D Activities

- Complementary efforts are underway in both public and private sectors.
- Sponsors include USDA, DOE, NASA, universities, state agencies, commodity groups, and sensor and satellite developers – the principal funding comes from USDA.

- Life-cycle analysis of tractor and irrigation pump emissions.
- Use of cover crops or mulch that would reduce or delay emissions.

Recent Progress

- High-resolution satellite imagery can identify stress and disease in some crops at 1-to-2-m resolution.
- Research programs have related reflectance spectra to disease or nutrient status.
- Control-release formulations for fertilizers and pesticides are in use.
- Rf-link deployable field sensors exist for ground moisture monitoring.
- On-farm use of yield-monitoring equipment is increasing.
- Commercial sensors for sensitive, precise, and rapid analysis of GHGs are now marketed.
- Best-management practices are in place for many crops and regions of the country.
- Genetically modified crop varieties are being used that are resistant to specific herbicides or pests.

Commercialization and Deployment Activities

- Global-positioning systems, geographic information system software for parameter mapping, remotely sensed imagery, selected field monitors, and selected variable rate control systems for seed, fertilizer, and chemical applications are commercialized and in application in the United States, Canada, Australia, and Europe.
- Slow-bleed release pesticides are available commercially.
- Nitrogen transformation inhibitors are available commercially, and were applied to approximately 10% of corn acres in 1996. Inhibitor application increased net revenue $8-$20/acre.
- Control-release fertilizers are produced and used mainly in horticultural and ornamental crops.

Market Context

- Market for technologies exists not only in the United States but worldwide. In developing countries dependent on agriculture, the market for improved agricultural systems is substantial.

4.2.2 METHANE REDUCTION OPTIONS FOR MANURE MANAGEMENT

Technology Description


Construction of a complete mix anaerobic digestion system

The livestock and poultry industry produces large quantities of manure each year. Pollutants from improperly managed waste can damage the environment in terms of water, air, and health quality. Methane and other gases are produced when manure is managed under anaerobic conditions typically associated with liquid or slurry manure-management systems such as lagoons, ponds, tanks, and basins. Methane reduction and other environmental benefits can be achieved by utilizing a variety of technologies and processes including aeration processes to remove and stabilize some pollutant constituents from the waste stream; anaerobic digestion system that collect and transfer manure-generated off-gases to energy producing combustion devices (such as engine generators, boilers, or odor-control flares); and solids-separation processes to remove some pollutant constituents from the waste stream.

System Concepts

- *Anaerobic digestion* provides a high level of manure treatment that mitigates water and other air pollution by biologically stabilizing (treating) influent waste materials and capturing methane emissions. Captured gas can then be combusted to produce electricity, heat, or vehicle fuel. Anaerobic digestion technologies can be applied at various scales (i.e., farm or centralized) and require separate effluent storage and a gas use device. Centralized anaerobic digestion technologies can be cost-effectively integrated into high-density livestock regions, where a number of farms would transfer manure to a dedicated processing facility. Centralized systems can produce very large power outputs (1-20 MW) depending on the manure volume and quality. Comparatively centralized systems can use technologies with greater complexity, because these plants typically have a professionally trained team available to operate the system.
- *Separation processes*, typically used in dairy operations, remove solid particulates from manure handled as liquid or slurry through gravity, mechanical, or chemical processes. These processes create a second waste stream that must be managed using techniques different from those already in use to manage liquids or slurries. Separation processes offer the opportunity to stabilize solids aerobically, such as in composting systems, to control odor and reduce pathogens. It is difficult to control methane emissions in uncovered lagoons or liquid manure storage facilities.
- In *aeration processes*, oxygen is transferred to a liquid primarily by mechanical equipment. The equipment serves to a) provide the oxygen needed by the microorganisms to oxidize the organic matter and b) keep the solids in suspension by mixing. A residual-dissolved oxygen concentration of at least 1-2 mg/L is an indicator that the rate of oxygen transfer is adequate to satisfy this oxygen demand aerobically for livestock waste. This requirement is usually met by large pumps operating in the range of about 50-125 HP.

Representative Technologies

- *Centralized digester technologies* include both mesophilic and thermophilic mixed digesters and other advanced environmental processes such as reverse osmosis and gas compression. Thermophilic digesters operate at high temperatures (140ºF). Mesophilic operate at lower temperatures (about 105ºF) and have greater process stability. Currently available combustion devices include medium-BTU reciprocating engines with heat recovery (cogen), turbines, boilers, absorption cooling, and furnaces. Flares also can be used to control odor and other air emissions in nonenergy applications. Emerging technologies include microturbines, sterling engines, and fuel cells.
- *Farm-scale digesters* are typically simpler systems operating at ambient and mesophilic temperatures and include mix, plug, and inground covered systems.

- *Separation process technologies* include gravity separation (shallow pits where solids settle and liquids run off to a treatment lagoon), mechanical separators (use external energy sources to remove solids), and flocculation or precipitation (chemical additions are used to help precipitate particulate and colloidal materials).
- A variety of *aeration process technologies* exist, including aerobic digestion (a suspended growth process operating at ambient temperature), autoheated aerobic digestion (utilizes heat released during the microbial oxidation of organic matter to raise process temperature above ambient levels), sequencing batch reactors (combine the conventional activated-sludge treatment process with secondary settling/clarification in a single tank), attached-growth processes (trickling filters, rotating biological contactors, and packed bed reactors use inert media to stabilize organic matter and limit organic loading rates), and composting (a solid-waste treatment process that requires oxygen and appropriate carbon:nitrogen ratios to heat and stabilize waste material.)

Technology Status/Applications

- There are currently about 150 anaerobic digesters producing heat and about 225 million kWh of electricity per year with currently available technologies at U.S. dairy and swine farms. A small number of farms also flare gas for odor control and GHG reductions. There are currently 3 centralized anaerobic digesters operating in the United States.
- Separation is typically used in the dairy industry to remove nonbiodegradable material from treatment lagoons, but is rarely applied to managing wastewater from swine facilities because swine solids are small, heavy, tend to mat, and hold water. Additional equipment and management is required to maintain adequate air infiltration for aerobic conditions.
- Aeration processes are basically applied to low-strength and dilute waste streams due to energy requirements. Their use has been limited for livestock liquid and slurry waste streams.

Current Research, Development, and Demonstration

RD&D Goals

- Develop new types of digesters with reduced costs and biological efficiencies. A number of private companies are developing and testing newer gas combustion devices for medium-BTU gases.
- Modification to under-slat floors in swine buildings to separate solid and liquid fractions and chemical additions applied to swine manure.
- Develop, apply, and evaluate aeration process performance for manure waste streams. Identify appropriate pollution-control methods for confined livestock facilities.

RD&D Challenges

- Current R&D on anaerobic digestion technologies is done at bench or pilot scales. These processes often are operationally complex at commercial scales. This complexity may be justified under a centralized operating structure because dedicated expertise is available to control system processes. This approach will also increase costs, and not necessarily energy, as most conventional digester technologies already convert the readily biodegradable manure component to biogas unless higher value organics are co-mingled with these advanced processes. Continued work in this area needs to identify regional areas with greatest opportunity to implement this approach relative to farm distances, manure-handling method, and frequency of collection.
- Utility policies toward independent power producers impede development of digestion technologies for power generation. Increasing operational reliability, efficiency, and costs of electrical production equipment and increasing the number of equipment providers is needed. Controller logic for electrical-producing gas uses and digester type also is required.
- Improved separation processes need to be demonstrated at commercial-scale farms where operations are more complex.
- Challenges for the use of aeration processes for primary manure treatment today include high investment and operating costs (including energy) of treating waste streams aerobically. Aeration processes also increase the volume of residual solids depending on the operating conditions necessitating removal and additional management. Aeration may also volatilize 30%-90% of the nitrogen as N_2 or N_2O, which can contribute to global warming and other environmental problems.

RD&D Activities

- EPA Region 9 is working with California to evaluate the feasibility of a centralized anaerobic project.
- USDA and DOE are currently funding research, development, and demonstration projects under the Biomass Research and Development Act of 2000. There are a number of projects focusing on technologies to generate energy from animal waste, convert biomass to hydrogen, and develop innovative biorefinery processes.

Recent Progress

- EPA's AgSTAR Program provides project development tools, performance evaluations, and general digester information. AgSTAR also collaborates with a number of state programs and various Farm Bill sections to expand the use of appropriate anaerobic digestion processes and gas uses. AgSTAR products and expertise have been used in the majority of animal waste digestion systems currently in operation.
- Currently, dairy manure handled as liquid and slurry is generally separated. Some dairies blend solids with other organic materials and market "brand" name compost materials for the nursery and home garden market.
- Aeration processes may be feasible for secondary or tertiary treatment of livestock waste, where greater pollution control is desirable – or to further reduce nitrogen availability for crop uptake.

Commercialization and Deployment Activities

- Currently, centralized digestion applications are being identified and some are in operation. The opportunities, however, may be limited because of farm distances and manure-handling practices. Biosecurity issues also may reduce the potential of this approach. Emerging gas-use technology development is limited for farm-scale anaerobic digesters because commercial applications have not been in operation long enough to make a performance determination by designers and vendors. However, applications at larger scales (such as landfill gas) will be relevant for centralized systems.
- There are several manufacturers and suppliers of mechanical separator equipment. USDA provides design guidance for gravity separators and technical resources to farms requesting assistance. USDA also provides cost share funds for proven technologies under the Farm Bill.
- A number of manufacturers and suppliers of aeration processes are available because it is used in municipal and industrial waste treatment. A number of low-rate aeration processes are emerging but have limited application because the dissolved oxygen requirements for microbial populations to oxidize organic matter are not met.

Market Context

- Cost-sharing and appropriate energy policies for independent power production could increase market penetration.

4.2.3 ADVANCED AGRICULTURAL SYSTEMS FOR ENTERIC EMISSIONS REDUCTION

Technology Description

Enteric emissions of methane from animals are a byproduct of digestion that are exhaled or eructated by the animals. It is a natural process, and the amount of methane emitted is dependent on the animal's digestive system and the amount and type of feed consumed. Because CH_4 emissions represent an economic loss to the farmer—where feed is converted to CH_4 rather than to product output—viable mitigation options can entail efficiency improvements to reduce CH_4 emissions per unit of beef or milk. There are a number of strategies that can be used, including increased digestibility of forages and feeds; feeding grain rather than forages; providing feed additives that may tie up hydrogen in the rumen and inhibit the formation of methane by rumen bacteria; improving production efficiency; and modification of bacteria in the rumen. Many production practices are currently used that reduce methane; when used individually or in conjunction with each other, the practices may lower the loss of methane energy up to one half. These have not only global change benefits but may have significant economic benefits as well. Most system concepts for reducing methane emissions are, however, theoretical, and considerable research and development are required. There has been minimal adaptation of practices to specifically reduce methane emissions from livestock.

System Concepts

- High-grain diets: Feeding of high-grain diets to reduce methane emissions and increase animal production efficiency, without contributing to the animal health problems that are typically associated with high-grain diets.
- Ruminal fermentation time: Methane is released from the rumen where feed is fermented in an anaerobic environment. The shorter the period of time feed remains in the rumen, the less carbon is converted to methane. Residence time in the rumen can be shortened by increasing the digestibility of feed grains or forages and by feeding of concentrated supplements.
- Alternate hydrogen acceptors: Addition of unsaturated edible oils in feed may be used to reduce methane emissions by sequestering hydrogen making it unavailable for methanogens.
- Use of feed additives: Ionophores are feed additives that inhibit the formation of methane by rumen bacteria. Considerable research is needed in maintenance of effectiveness for long periods and for delivery systems to grazing cattle.
- Improvement in production efficiency: Any practice that increases productivity per animal reduces methane emissions. Animal technologies that increase productivity include BST to increase milk production, growth regulators for beef cattle to enhance lean and reduce fat, genetic improvement of animal performance, genetic improvement of pasture and other feedstuffs potential, improved animal feed-handling practices, improved pasture nutritional and water management, and earlier marketing of animals.
- Enhancing ruminal acetogens: Acetogens are a group of rumen microbes that produce acetic acid from hydrogen and carbon dioxide rather than methane. They exist in the rumen as a minor species, predominate in the gut of some termites, and may be important in the lower gut of several animal species. Developing methods to make them more competitive in the rumen or transferring the acetogenesis genes to already successful ruminal organisms could be very helpful to animal efficiency and the environment.
- Modification of bacteria in the rumen: Alteration of ruminal microbes may lead to significant reduction in methane emissions; however, considerable research is needed to genetically produce microbes that can compete with natural microbes for sustained periods.

Representative Technologies

- Improved feed and forage management and treatment practices to increase the digestibility and reduce residence digestion time in the rumen, such as using improved feed grains and forage, increased surface area of the feeds, addition of fiber sources, treatment of the feeds/forages to increase digestibility, and appropriate use of concentrated supplements.
- Best-management practices for increased animal reproduction efficiency.
- Use of growth promotants and other agents to improve animal efficiency and enhance lean meat production.

Technology Status/Applications

- Strong understanding of animal physiology exists in the agriculture, energy, and university research areas.
- Research is required for the development of control-release materials and biological process inhibitors.

- Extensive use is made of animal and feed technologies in dairy- and beef-feeding systems; however, adequate techniques for uniform and effective delivery systems are needed in grazing systems.
- Best-management practices are in place in many production sectors.

Current Research, Development, and Demonstration

RD&D Goals

- Precision agriculture technologies that will improve forage and feedstuffs production efficiencies and increase digestibility.
- Smart materials for prescription release of feed additives under pasture or grazing systems.
- Genetic improvement of forages to increase productivity and digestibility.
- Methods of manipulating ruminal microbial processes to sequester hydrogen making it unavailable to methanogens.
- Deployment of first-generation integrated system models, technology and supporting education, and extension infrastructure.
- Genetically design forages to increase digestibility, reduce fertilizer requirements, provide chemicals for increased digestibility, and provide appropriate nutrients to enhance acetogen competitiveness.
- Genetically design bacteria that can compete with natural microbes for sustained periods.
- Full utilization of best-management practices.

RD&D Challenges

- Precision agriculture requires advances in rapid, low-cost, accurate plant, soil-nutrient, and physical property characterization; real-time crop and forage water requirements characterization; real-time crop and forage yield and quality characterization; real-time insect and pest infestation characterization; autonomous control systems; and integrated physiological model and comprehensive and user-friendly data/information-management systems.
- "Smart" materials that will release chemicals and feed additive doses under special conditions.
- Improved understanding of specific rumen microbial processes is required to support development of methods for making engineered microbes competitive with natural rumen microbes.
- Models that represent accurate understanding of the relationship of animal digestion and plant physiology must be coupled with models that represent soil-plant growth relationships. These models also must consider the changing global climate.
- Genetic engineering of sustainable competitive microbes that will produce acetic acid for the reduction of CO_2 with hydrogen.
- Development of plant varieties that increase nutrient-use efficiency while enhancing digestibility.
- Conduct direct basic and applied research effort on animal physiology, sensor development, material and feed additive research, and microbial processes research.

RD&D Activities

- The principal funding for this type research comes from the USDA and the animal-support industries. Others include the EPA, universities, state agencies, commodity groups, and instrumentation developers.

Recent Progress

- Success has been observed under grazing in the use of ionophores, which are widely used in the beef industry.
- Control-release formulations for fertilizers and pesticides are in use, which improve forage productivity and digestibility.
- Animal productivity per unit of methane emissions has steadily increased under managed conditions in the past 30 years.
- On-farm use of yield-monitoring equipment is increasing.
- Commercial sensors for sensitive, precise, and rapid analysis of greenhouse gases are in development and being marketed.
- Best-management practices are in place for many crops and animal-management systems and regions of the country.

Commercialization and Deployment Activities

- Global-positioning systems, geographic information system software for parameter mapping, remotely sensed imagery, selected field monitors, and selected variable rate-control systems for seed, fertilizer, and chemical applications are commercialized and in application in the United States, Canada, Australia, and Europe. All of these systems may be used for increasing productivity and digestibility of forages.
- Mitigated-release fertilizers and pesticides are available commercially.
- Ionophores are widely used in the beef-feeding industry to increase productivity – but better delivery systems are needed.
- Current precision agriculture technology is proven to be cost effective about 50% of the time, with poor reproducibility.
- The infrastructure in place for agricultural production will support economical new technologies; however, the cost to compete with traditional technologies may initially be high until technology integration is complete.