Whole Farm Evaluation of Nutrient Management

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Nutrient management has become a major issue in many regions of the country. Areas with the greatest concern are those in nutrient sensitive watersheds. Farms of all sizes are being impacted, but larger farms are being watched most closely by governmental regulatory agencies and society as a whole.

The nutrients of primary concern are nitrogen (N) and phosphorus (P). Management to better utilize either of these nutrients is complex, and managing both together is considerably more complex. Nitrogen is lost through volatilization to the atmosphere, runoff in surface water, and leaching into groundwater. Volatilized N is primarily in the form of ammonia. Ammonia emissions are of increasing concern because ammonia in the atmosphere leads to the creation of small particulate matter with potential human health concerns. Atmospheric ammonia also contributes to over fertilization, acidification, and eutrophication of ecosystems, which may occur near or a considerable distance from the ammonia source. Microbial processes during manure storage and in the soil following field application also emit nitrous oxide to the atmosphere. Nitrous oxide is a potent greenhouse gas that is contributing to the concern for global warming. Minor amounts of nitric oxide and nitrogen dioxide may also be emitted, and these gases may interfere with tropospheric ozone production.

Leaching of nitrates to ground water has been the major concern for N loss. Heavy rainfall, particularly in the late fall through early spring period when soil moisture levels are high, carries nitrates through the soil profile into the groundwater below the root zone of the crop. Groundwater from wells with an N concentration in excess of 10 ppm is potentially harmful to human health, particularly for infants and small children. Surface runoff of N can also occur, primarily in the form of nitrate. This loss is small, but it contributes to the eutrophication of surface waters along with soil drainage loss and acid rain.

Phosphorus is more stable than N during manure handling and following field application, and thus losses are relatively small. Phosphorus does not volatilize and move into the atmosphere; loss only occurs through surface runoff or leaching into groundwater. On most soils, leaching loss is small and unimportant. In course-textured soils though, some soluble P can be carried through the soil profile with excess soil moisture. This can be a concern for tile-drained fields where this P is carried back to surface water. Most P loss occurs through erosion and the associated surface runoff. Phosphorus in surface water leads to the eutrophication of streams and lakes. Eutrophication can kill fish and other aquatic life, deter recreational use of lakes and streams, and increase the cost of obtaining drinking water from these water sources.

A number of management options can be used to improve nutrient utilization on the farm and thus reduce loss to the environment. Finding a cost effective approach though, can be a challenge. A whole farm approach must be taken when considering management changes to improve nutrient utilization. Focusing on the reduction of loss from one part of the farm is of little value if that change just leads to additional loss on another part of the farm. For example, reducing N loss in the barn can simply lead to greater loss during manure storage and field application if all components of the farm are not equally managed. Thus, whole-farm management can become very complex and difficult. Many forms of computer software are being developed and used to help integrate farm information and simplify this management process. In particular, whole-farm simulation provides a useful tool for evaluating and comparing the long-term farm performance, economics, and environmental impact under alternative management scenarios.

Nitrogen Management

Nitrogen is an essential element in animal production. Large quantities of N are required for the growth of feed crops. Crop N, primarily in the form of protein, is then an essential feed component for animal growth and development. Most of the N consumed is excreted by animals providing manure nutrients needed for crop growth. The problem in this cycling of N is that large losses to the environment normally occur. The challenge is to manage the animals, crops, and other farm components to efficiently use or transfer available N, and thus reduce loss.

Management processes are available or under development that reduce N loss, but implementation often remains a challenge due to various constraints (Rotz, 2004). The primary constraint is usually economic. New management practices often require large investments or greater operating costs that are difficult to justify. Profit margins are low in most animal operations, and the direct economic return for saved nutrients is small considering their fertilizer replacement value. Labor can also be a constraint. Available labor is often heavily used in animal production, so changes that require more time, particularly for the farm manager, will not be readily accepted.

Reducing N loss from the farm must begin with proper animal feeding and management to improve the N use efficiency of the animals and thus reduce N excretion. On dairy farms today, 20 to 30% of the N consumed by the herd is in the protein of the milk and meat produced with the remainder excreted in manure. Pasture-fed dairy animals are at the lower end of this range, and pasture produced beef animals have an N use efficiency of less than 10%. When finishing beef in a feedlot, again only about 10% of the N intake is retained in body tissue.

Thus, large amounts of N are excreted in dairy and beef production. Nitrogen excretion is directly related to the animal's N (protein) intake, so less protein must be fed per unit of production to reduce N excretion. Two general strategies can be used to reduce N excretion. The first is to reduce the protein fed by improving the match between the protein quality fed and that required by the animal. The other is to improve animal productivity. As more milk or meat is produced per animal, the maintenance requirement of protein per unit of production is reduced. Thus, the animal product can be produced with less N consumed and excreted. Although improved productivity can increase N use efficiency, greater improvements are generally obtained through strategies that improve protein-feeding efficiency. By reducing excreted N, losses throughout the remaining N cycle are potentially reduced.

Even with good animal and feeding management, large quantities of N are in the manure. A major portion (about half) of this excreted N can transform to ammonia, which may volatilize into the atmosphere. Volatile loss begins soon after excretion, and it continues through all manure handling processes until the manure nutrients are incorporated into soil. Major points of loss are in the barn, during manure storage, and immediately following field application.

When manure is deposited on the barn floor, urea from the urine quickly transforms to ammonia, which readily volatilizes. Under cold winter conditions, this process is slow and loss is relatively low. Under warm summer conditions, up to half of the total N excreted (essentially all urine N) can be lost from the barn. Averaged over the year, about 15 to 20% of the total N excreted is lost from a typical free-stall barn (Rotz, 2004). For a tie stall barn, about half this loss occurs, but with an open feedlot, this loss is more than doubled. Experimental floor systems are being tested in free-stall barns to drain the urine away from the feces. This slows the formation of ammonia, reducing barn loss by about 50%.

The loss during manure storage depends upon the type of storage and the amount of loss that has occurred in the barn. If much of the ammonia N has been lost prior to storage, less is available to loose from the storage. When manure is stored as a slurry in a tank, about 30% of the total N entering the storage can be lost by the time it is removed (Rotz, 2004). However, if the manure slurry is pumped into the bottom of the tank allowing a crust to form on the surface, this loss can be reduced to about 8% of the total N stored. In an anaerobic lagoon, losses are very high, varying between 50 and 100% of the total N entering storage. Covered manure storages can be used to reduce storage loss to less than 5%.

Nitrogen loss following field application varies with the amount lost prior to application and the application method (Rotz, 2004). For broadcast slurry, average N losses are about 20 to 25% of the total N applied. This loss is a little higher around 30% for irrigated liquid manure. This loss can be reduced by incorporating the manure into the soil within a day of application. By direct injection into the soil, loss following application can be reduced to less than 5% of the total N applied.

If steps are taken to maintain the N until it is incorporated into the soil, leaching and denitrification losses of soil N will increase if that N is not applied at the appropriate amount and time for crop uptake (Rotz, 2004). When manure is applied in the fall or winter on fallow soil, over 25% of the total N incorporated into the soil can be lost through leaching and denitrification processes. When applied just prior to planting or on a growing crop, these losses should be relatively small since the N can be readily taken up by the crop. If excessive amounts of N are applied though, that not used by the crop will be lost in some form. When manure is applied in the fall, losses can be reduced using small grain and grass cover crops, which take up the soil N and carry it through the winter months stored in plant tissue.

Phosphorus Management

Phosphorus loss from farms primarily occurs through water flow. Some of this P is water soluble, and thus is dissolved and carried by water moving across the soil surface during storm events. Insoluble P can also move in small soil or manure particles eroded and carried by the moving water. On some soils, substantial amounts of P, particularly soluble P, can leach through the soil profile and move back to the surface through drain tiles.

There are two management approaches to reducing P loss from farms. The first is to reduce water and nutrient flow from the farm, and the other is to reduce the amount of excess P accumulated in the soil on the farm. One of the best ways to reduce water flow and the resulting erosion is to maintain a perennial crop such as grass on the soil surface. Another strategy is to use reduced tillage or no-till systems for crop establishment. By leaving more crop residue on the soil surface, water flow and erosion are impeded holding more of the moisture and nutrients in the soil and on the farm.

Another strategy is to avoid applying P on land areas that are very susceptible to loss. Many states now use a P index to identify field areas that are most susceptible to erosion and the movement of P. By applying manure on areas less susceptible to runoff, the amount of P moving off the farm in storm events can be reduced.

Ultimately, the best long-term solution to reducing P loss is to avoid the accumulation of soil P on the farm and the very high soil P levels that result from this over application. Reducing water flow and the erosion of soil P should be viewed as only a temporary solution if excessive amounts of manure P are being returned to the land. Eventually, the accumulation of soil P on the farm will lead to excessive loss to the environment in spite of measures taken to contain this loss. In order to maintain long-term sustainability of the farm, a P balance should be maintained over the whole farm and over individual fields within the farm.

To maintain a P balance on the farm, the P leaving the farm must be greater than or equal to that imported. This requires that most of the feed for the herd be produced on the land to which the manure nutrients are returned. This limits the number of animals maintained per unit of land. This maximum stocking rate will vary with crop and feeding management, but a typical requirement is around 2.5 acres per dairy cow including her replacement. By improving feeding efficiency, this limit may be decreased to about 2.2 acres per cow. If replacement heifers are not raised on the farm, the land requirement is in the range of 1.8 to 2.0 acres per cow.

Phosphorus is primarily imported in purchased feeds and fertilizers. Use of mineral fertilizer should be avoided on fields with high soil P levels or when manure is available. The best way to reduce feed imports is to reduce or eliminate the supplemental mineral P fed. Recent research has shown that the high levels of supplemental P traditionally used in dairy diets are not necessary. Dietary P levels currently recommended by the National Research Council (2001), and perhaps even lower levels, can be maintained without compromising the production, reproduction, health, and wellbeing of cattle. Depending upon the type of supplemental protein feeds used, little or no additional mineral P may be required in diets. This often reduces the feed cost of the producer while reducing the accumulation of soil P on the farm. Some feed supplements high in P content may also need to be substituted with other feeds. Depending upon feed prices, this may require an increase in feed cost for the producer.

Therefore, a number of management changes can be made to help improve P utilization on the farm and reduce loss to the environment (Rotz et al., 2002). The first step should always be proper feeding. Mineral P fed and the P concentration in supplemental feeds should be reduced to avoid overfeeding of P. Second, mineral P fertilizer should not be used when manure is available or soil tests indicate that additional P is not needed. If these adjustments do not allow a long-term P balance for the farm, animal numbers should be reduced and/or land area should be increased to maintain a proper stocking rate. If this is not feasible, the alternative is to export manure P from the farm as compost, manure solids, or raw manure. When a farm balance is obtained, short-term P loss from the farm can be reduced through greater use of perennial crops and conservation tillage practices, and by avoiding manure application to land areas most susceptible to erosion and P movement in surface water flow.

Whole Farm Evaluation

Nutrient management planning requires a whole farm analysis to improve nutrient use while maintaining or improving farm profitability. Many factors must be considered along with the many interactions that occur among farm processes. Considering all these aspects together becomes very complex, and perhaps beyond human ability. Computer simulation provides a tool for integrating all the necessary information to obtain a long-term evaluation of farm production systems. One particular model, the Integrated Farm System Model or IFSM, was develop as a research and teaching tool for evaluating and comparing the performance, economics, and environmental impact of alternative crop, dairy, and beef farm production systems.

The Integrated Farm System Model simulates the many biological and physical processes on farms (Figure 1; Rotz and Coiner, 2004). Crop production, feed use, and the return of manure nutrients back to the land are simulated over many years of weather. Growth and development of grass, alfalfa, corn, soybean, and small grain crops are predicted on a daily time step based on soil and weather conditions. Manure handling, tillage, planting,

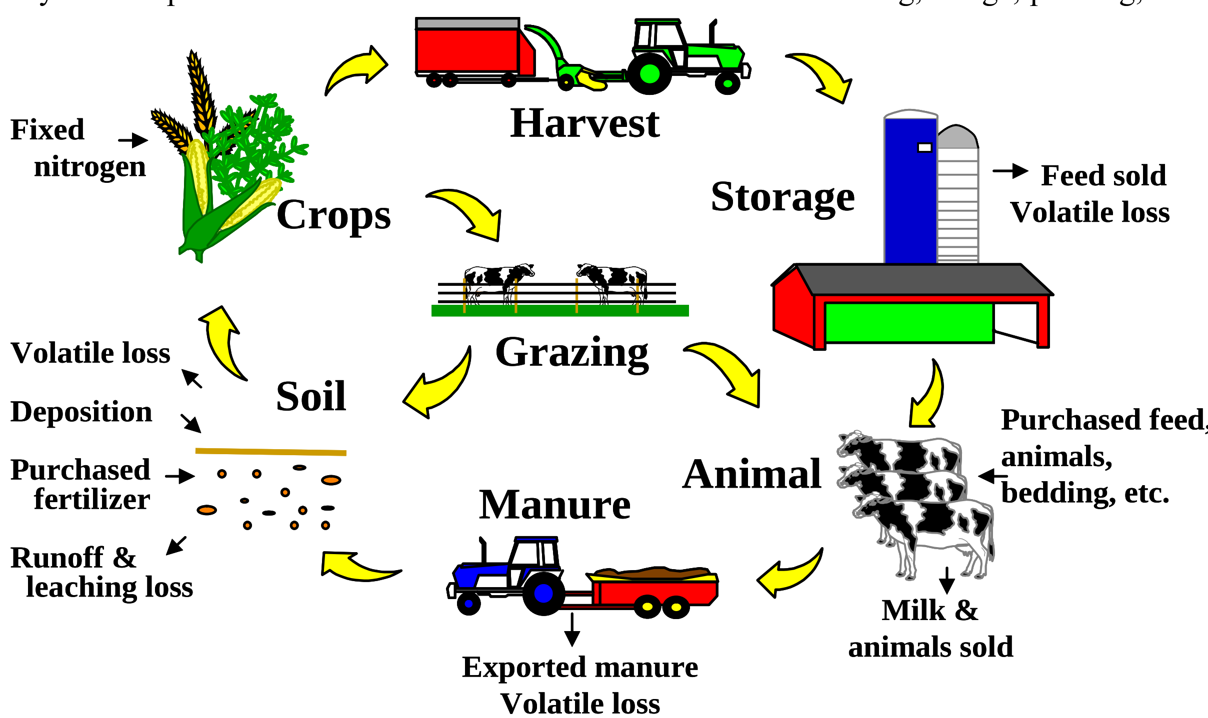

Figure 1. The Integrated Farm System Model simulates material and nutrient flows for various farm production systems over many years of weather to predict the long-term performance, environmental impact, and profitability of the farm.

harvest, and storage operations are simulated to predict resource use, timeliness of operations, crop losses, and nutritive changes in feeds. Feed allocation and animal response are related to the nutritive value of available feeds and the nutrient requirements of the animal groups making up the herd.

Nutrient flows through the farm are modeled to predict potential nutrient accumulation in the soil and loss to the environment (Rotz and Coiner, 2004). The quantity and nutrient content of the manure produced is a function of the quantity and nutrient content of the feeds consumed. Nitrogen volatilization occurs in the barn, during storage, and between field application and soil incorporation. Denitrification and leaching losses from the soil are related to the rate of moisture and nutrient movement through the soil profile as influenced by soil properties, rainfall, and the amount and timing of manure and fertilizer applications. A whole-farm balance of N, P, and K considers the import of nutrients in feed and fertilizer and the export in milk, animals, excess feed, and manure. Supplemental P and K fed, if needed, is the difference between the requirement of each animal group and the sum of that contained in the feeds consumed.

Simulated performance is used to predict production costs, income, and farm net return or profit for each simulated year of weather. A whole-farm budget is used where investments in equipment and structures are depreciated over their economic life, and the resulting annual costs are added to other annual expenditures and incomes determined for each year. By simulating several production options, the effects of system changes are compared including resource use, production efficiency, environmental impact, and net return.

All farm parameters, including prices, are held constant throughout the simulation so that the only source of variation among years is the effect of weather. Distribution of the annual values obtained can then be used to assess the risk involved in alternative technologies or strategies as weather conditions vary. Using statistical terminology, each system alternative can be considered a treatment where each simulated year is a replicate of farm performance for the specific weather conditions of the year. Thus, a multiple year simulation provides an estimate of the frequency or probability of attaining a certain level of system performance or profit. A wide distribution in annual values implies a greater degree of risk for a particular alternative.

Model Input. Input information is supplied to the program through three parameter files. The farm parameter file contains data describing the farm. This includes crop areas, soil type, equipment and structures used, numbers of animals at various ages, harvest, tillage, and manure handling strategies, and prices for various farm inputs and outputs. The machinery file includes parameters for each machine available for use on a simulated farm. These parameters include machine size, initial cost, operating parameters, and repair factors. Most farm and machinery parameters are modified quickly and conveniently through the menus in the user interface of the program. Many of these files can be created to store parameters for different farms and machinery sets for later use in other simulations.

The weather data file contains daily weather for many years at a particular location. Weather files for about twenty locations are available with the model, and new files may be created for other locations. All files are in a text format so they can be created or edited with most spreadsheet and text editors. When creating a new weather file, an exact format must be followed. The first line contains a site code, the latitude and longitude for the location, the atmospheric carbon dioxide level, and a code for the northern or southern hemisphere. The remainder of the file contains one line of data for each day. The daily data includes the date, amount of solar radiation, maximum and minimum temperature, and total precipitation.

Model Output. The farm model creates output in four files. Following a simulation, the files requested appear in overlaying windows within the primary IFSM window where they can be selected and viewed. These output files contain summary tables, report tables, optional tables, and parameter tables. The summary tables include the average performance, costs, and returns over the number of years simulated. These values consist of crop yields, feeds produced, feeds bought and sold, manure produced, costs of manure handling and feed production, other farm costs, income from products sold, and the net return or profitability of the farm. Values are provided for the average and standard deviation of each over all simulated years.

The report tables provide extensive output information including all the data given in the summary tables. Additional data includes planting and harvest dates, forage field curing times, crop quality, feed utilization, nutrient losses, and the water and nutrient balances for the farm. In these tables, values are given for each simulated year as well as the mean and variance over all simulated years.

Optional tables are available for a closer inspection of how the components of the full simulation are functioning. These tables include daily values of crop growth and development, a summary of the suitable days for fieldwork each month, daily summaries of forage harvest operations, annual summaries of machine, fuel, and labor use, and a description of how animals are fed. Optional output is best used to verify or observe some of the more intricate details of a simulation. This output can be very lengthy, and as such, is only available when requested.

Parameter tables summarize the input parameters specified for a given simulation. Any number of these tables can be requested where the tables are grouped according to the major sections of model input. These sections include crop, soil, tillage and planting parameters, grazing parameters, machine parameters, harvest parameters, storage and preservation parameters, herd, feeding, and manure parameters, and economic parameters. These tables provide a convenient method for documenting the parameter settings for specific simulations.

Model Application. The Integrated Farm System Model has been used to evaluate many production strategies. For example, a comprehensive simulation study illustrated that more efficient feeding and use of protein supplements could increase farm profit and reduce N loss (Rotz et al., 1999). Compared to soybean meal as the sole protein supplement, use of soybean meal along with a less rumen degradable protein feed reduced the annual volatile N loss by 12 to 30 lb/acre of cropland with a small reduction in N leaching loss (about 1 lb/acre). Using the more expensive but less degradable protein supplement along with soybean meal improved annual net return by \$46 to \$69/cow dependent upon other management strategies used on the farm. Environmental and economic benefits from more efficient supplementation of protein were generally greater with more animals per unit of land, higher milk production levels, more sandy soils, or a daily manure hauling strategy. Relatively less benefit was obtained when either alfalfa or corn silage was the sole forage on the farm or when relatively high amounts of forage were used in animal rations.

A comprehensive study evaluated management changes for dairy producers in southeastern New York to reduce the potential loss of P to the surrounding watershed while maintaining or improving farm profitability (Rotz et al., 2002). Several production options were found to reduce or eliminate the long-term accumulation of soil P while increasing profit. The best options were those that reduced the P fed to dairy cows and maximized the use of forage grown on the farm. The most easily implemented change was to reduce the supplemental mineral P fed to that required to meet current recommendations (NRC, 2001). This provided an annual increase in farm profit of about \$22/cow. Intensifying the use of grassland and improving grazing practices increased profit along with a small reduction in excess P. Conversion from dairy production to heifer raising or expansion from 100 cows to a 250-cow "state-of-the-art" confinement facility (with a 70% increase in land area) were also profitable options. These options provided a long-term P balance for the farm as long as the production and use of forage was maximized and minimum dietary P amounts were at the recommended levels.

Model availability. The Integrated Farm System Model is available from the Internet site of the Pasture Systems and Watershed Management Research Unit (http://pswmru.arsup.psu.edu). The program operates on computers that use any Microsoft Windows® operating system. To obtain a copy of the program, including an integrated help system and reference manual (Rotz and Coiner, 2004), the Internet site can be accessed at the address given where instructions for downloading and setting up the program are provided.

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