Nutritional and Management Practices to Reduce Excessive Nutrient Excretion on Dairy Farms

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(ABSTRACT)

A 2-yr field study was conducted to reduce nutrient losses from Virginia dairy farms through nutritional and herd management practices. Ten collaborator herds were identified, all at state DHIA average or better for milk yield and days open. Baseline feed samples and ration information were collected for 2 mo and analyzed for phosphorus (P) and nitrogen (N). Feeds were analyzed monthly, and monthly DHIA milk yield, milk composition, milk urea N (MUN), and reproductive data were recorded. Blood and fecal samples were collected from 25 cows/herd every 3 mo to monitor P excretion and blood urea N. Nutrient balances were developed for each farm for N and P at the start of the study and following ration and management changes. Collaborator herds imported, on average, 290% more N and 320% more P onto the farm than was removed through milk, culled animals, crop sales, or manure sales. By following NRC (1989) recommendations, collaborator farms could reduce N inputs by 21% and P inputs by 45%. Minimizing P in purchased feed, purchased feeds/cow, purchased feeds/ha, and total P input could cause significant reductions in P balance for participating collaborator herds. None of the N variables tested (purchased feed, purchased feed/cow, purchased feed/ha, and total N input) provided significant reductions.

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Introduction

As dairy farm operations become more intensive, nutrient management becomes an important issue and has become a concern of environmental groups as well as the government (Parry, 1998). Intensive dairy farming, along with increased use of imported feeds, leads to increases in quantities of waste to be spread on farm acreage. Even though cow numbers per farm have increased, farm crop acreage has remained unchanged, which has resulted in nutrient accumulation in the soil (Lanyon, 1992; Sharpley et al., 1998). Nutrients then run off into streams, leach into ground water, and/or volatilize into atmospheric gases.

Proper nutrition programs and management of dairy operations can minimize the risk of nutrient pollution (Mandersloot et al., 1995; Chase, 1999). In addition, monitoring forage quality, balancing dairy rations based on National Research Council (NRC, 1989) recommendations, and education through Dairy Advisory Team (DAT) meetings can reduce extraneous nutrient excretion. Likewise, milk urea nitrogen and nutrient balancing spreadsheets can also be used to help monitor nutrient flow within the dairy farming system.

Dairy Advisory Teams are effective in producing management decisions that lead to increased farm profitability (Heald, 1999). The sole purpose of DAT is to increase farm sustainability and improve dairy management decisions through combined interaction and discussion among producers, veterinarians, nutritional consultants, lenders, and extension agents. Thus, communication and interaction between every segment of the dairy industry is essential in making sound decisions that affect not only farm profitability, but also environmental conservation.

Nutrient management should be a key topic discussed during DAT meetings. As soil sample tests are returned to dairy operations with increasing P accumulation, pollution becomes a major concern. By accurately measuring nutrient flow on farms, dairy producers can alter quantities and types of nutrients entering or leaving their property. Ideally, all nutrients entering farms would be removed, but with increasing numbers of confinement operations with more than one species, surplus nutrients are remaining on the farm.

Objectives of this study were to document and record nutrient loading to farm acres from a sample of Shenandoah Valley dairy farms, and to demonstrate how nutritional changes could potentially reduce nutrient excretion. During the project, dairy producers were informed and educated about nutrient management of farm waste through the use of nutrient balancing spreadsheets, milk urea nitrogen analysis, forage and blood serum analyses, and by participating in DAT meetings. It was anticipated that participation in this field study would lead to the implementation of nutrient-based management decisions and other management practices deemed necessary for profitable dairy production.

Review of Literature

Environmental Concerns

Overview

Animal agriculture is the primary nonpoint source of nutrients entering most watersheds (Lanyon, 1994; Van Horn et al., 1996; Jonker, 1998; Ertl et al., 1998; Sauer et al., 1999). As dairy farming changes over time, certain practices could lead to measurable point sources of pollution, such as fertilizing fields with manure with runoff being monitored in nearby streams (Frink, 1969; Lanyon, 1994; Van Kessel et al., 1999). Currently, only concentrated animal feeding operations (CAFO) with >1000 animal units (AU) are considered point sources of pollution. However, as technology advances, fertilization with dairy wastes could lead to point sources of pollution by measuring units of nutrient accumulation in the soil, subsurface runoff of nutrients, eutrophication, and other gaseous losses of ammonia and nitrous oxide to the atmosphere (Korevaar, 1992; Mandersloot et al., 1995, Van Horn et al., 1996; Grusenmeyer and Cramer, 1997; Hof et al., 1997; Daniel et al., 1998; Ertl et al., 1998; Jonker, 1998; Parry 1998; Sharpley et al., 1998; Sims et al., 1998; Gallimore et al., 1999; Schmitt et al., 1999; Jonker, 1999).

Because regional soil and water quality problems exist, new management strategies should be explored to move nutrients off farm, and to use manure as fertilizer on surrounding soils (Van Keulen, 1982; Kohn, 1996; Van Horn et al., 1996). Land management, nutritional strategies, and waste management should be utilized to help reduce the amount of P and N either leaching into ground water and/or running off into surface bodies of water (Korevaar, 1992; Mandersloot et al., 1995; Hof et al., 1997; Ertl et al., 1998; Jonker, 1998; Jonker, 1999; Schmitt et al., 1999).

When feeding agricultural by-products to dairy animals and recycling waste back to plants that need nutrients, food animal production farms can have a positive effect on the environment (Van Horn et al., 1996). Farmers should continue to find a balance between environmental awareness and responsible, efficient, and profitable livestock production systems (Chase, 1999). Farms will need to design dairy management systems that result in positive feedback from surrounding neighbors. A positive farming perception by urbanites could lead to an enhanced growth of dairies and a deeper respect for all types of farming. Alternatively, if current practices persist, public annoyance will continue to grow and dairy farms in regional locations could be forced to move or dissolve their operations (Lanyon, 1994).

Dairy farming sustainability in any country will rely on the ability of farms to produce crops and milk efficiently without disrupting the natural environment. Farmers need to understand the environmental impacts of spreading excessive nutrients. One possible alternative is to quantify the sustainability of a system, because there are many factors that control sustainability of a dairy farming system (Van Keulen, 1982). Quantification of dairy sustainability can be measured using nutrient use efficiencies. Nutrient use efficiencies are simple ratios that measure amounts of exports compared with amounts of imports, and provides tangible numbers that producers can understand (Van Keulen, 1982). If farm management is improved, there is less potential for nutrient leaching or runoff. Producers along with support staff, such as nutritional consultants, veterinarians, extension agents, and surrounding communities can correct excess nutrient problems together.

Environmental Concerns Involving N

Leaching of N is an environmental concern that has been addressed. In research trials, soil leaching of N has been estimated at 9% of total N inflows using the LEACHN program (Hutson et al., 1998). Research has indicated that there are adverse effects on human health and the environment as a result of N pollution (Schmitt et al., 1999). One particular human illness associated with excessive nitrate levels in ground water is "blue baby syndrome" otherwise known as methemoglobinemia. This condition limits the O_2 carrying capacity of blood, providing insufficient amounts of O_2 to body organs. Not only is this condition found in babies, but also in older adults. Humans suffering from methemoglobinemia show tints of blue around the mouth, feet, and hands. Severe cases have been known to cause death in infants (Hart et al., 1997). Likewise, excessive nitrate levels in surface water have been linked to massive fish kills and other aquatic losses due to surface water eutrophication (Hutson et al., 1998). Eutrophication is a process in which excessive discharge of N and P to surface waters causes proliferous algae production, in turn, causing a reduction in submerged vegetation. Decomposition of algae removes dissolved oxygen from the water resulting in fish kills.

Total farm N utilization has been measured between 14 and 17% of total N inputs for intensively managed dairy farms (Paul et al., 1998). The other 83 to 86% is either leached as NO_3, volatilized as NH_3, emitted as N_2O or NO, or is accumulated in soil. The proportion lost via each route varies with differing soil types and compositions (Korevaar, 1992; Paul et al., 1998; Cambardella et al., 1999). Nitrogen is lost mainly by volatilization of ammonia, denitrification in the soil, leaching, surface runoff, and used by crops to increase yields (Van Horn et al., 1996).

It is expected that 50 to 80% of N from manure will volatilize before being spread (Frink, 1969; Van Horn et al., 1997). During manure spreading, 25 to 35% of N is lost due to ammonia volatilization (Sauer et al., 1999). Other studies have shown that almost 100% of N in urine could be volatilized as ammonia within days of application (Sauer et al., 1999). Remaining N was denitrified in the soil, leached, ran off, or was used by growing crops within the next 3 wk (Sauer et al., 1999).

An estimated 82% of total N inputs to a dairy farming operation can be accounted for in milk (25%), animals (2%), leaching (9%), and volatilization/denitrification (46%) (Hutson et al., 1998). Of the remaining 18% of total N inputs, environmental losses accounted for 75% (Hutson et al., 1998).

Environmental Concerns Involving P

Phosphorus contamination of ground and surface water has become a critical environmental issue (Sauer et al., 1999). The dairy industry is overfeeding P to its animals, which is not only costing the industry over $100 million dollars annually, but has led to eutrophication of surface bodies of water from soil runoff (Morse, 1996; Hart et al., 1997; Correll, 1998; Satter and Wu, 1999; Van Kessel et al., 1999).

Phosphorus is considered the limiting nutrient for algae growth (potentially leading to eutrophication) in surface bodies of fresh water (Hergert et al., 1981a; Hergert et al., 1981b; Daniel et al., 1998). Surface waters usually are able to retain P in bottom sediment, where P is converted to orthophosphate and is used by algae, bacteria, and plants (Correll, 1998). Algae, bacteria, and other plants flourish with increased orthophosphate levels, leading to eutrophication (Correll, 1998). As the bloom grows, algae increase respiration rates, leading to hypoxia and anoxia in water sources (Correll, 1998). Reduction in dissolved oxygen in water results in fish kills and loss of other aquatic life forms (Correll, 1998).

Cyanobacteria are also associated with P pollution (Daniel et al., 1998). Consumption of cyanobacteria can kill livestock and pose serious health threats to humans (Daniel et al., 1998; Sharpley et al., 1998).

Large dinoflagellate *Pfiesteria piscicida* outbreaks have been noted around the Chesapeake Bay Watershed, which are associated with excessive nutrients entering surface waters (Sharpley et al., 1998). This dinoflagellate produces highly toxic and volatile chemicals that may cause neurological damage in persons (Sharpley et al., 1998). Due to this outbreak, there has been increased awareness of nutrient pollution of watersheds (Sharpley et al., 1998).

In an effort to control algae blooms leading to eutrophication, researchers have proposed critical values to monitor P in the water. Critical values for surface water P are between .01 and .025 mg/L (Hergert et al., 1981a; Hergert et al., 1981b; Daniel et al., 1998). The critical value of P for flowing bodies of water should not exceed .05 mg/L or there is potential for eutrophication to take place (Daniel et al., 1998). Values above the previously listed ranges are optimal for algae bloom (Correll, 1998; Daniel et al., 1998; Parry, 1998).

One manner in which P enters waterways and surface waters is through soil runoff from the over-application of dairy wastes or commercial fertilizers. There are two forms of P that could potentially runoff from soils with high levels of P (Correll, 1998; Daniel et al., 1998). The first is particulate P, which is found in eroded soils from heavily fertilized lands and constitutes anywhere from 60 to 90% of runoff P. The other P source is dissolved P, which is immediately used by surrounding plants (Daniel et al., 1998). Because there is considerably less P leaching through the subsurface, most research has been dedicated to understanding how P moves across land and into streams and large bodies of water (Sims et al., 1998). Many researchers have ignored subsurface runoff or leaching that may occur, but given certain soil types, P pollution through these two pathways may be significant (Sims et al., 1998).

Runoff of P from agricultural lands has been a worldwide problem for more than 30 years (Sims et al., 1998); thus, a specialized test has been developed to determine which fields are most susceptible to P runoff. The P Index uses soil test data, soil erosion and runoff potentials, P fertilizer or organic waste application rates, and method and timing of P fertilizer in order to calculate a field rating. Subsequent field measurements and ratings will determine which fields are susceptible to runoff (Sims et al., 1998). The higher the P index numbers, the greater the possibility of P runoff. Other tests have been developed using similar measurements that were used to develop the P Index.

Other research has focused on the use of chemical amendments and water treatment residuals to reduce P runoff. Chemical amendments, such as Ca, Al, and Fe, were used successfully to reduce amounts of P runoff when mixed with poultry litter (Gallimore et al., 1999). These chemical amendments bind the P to the molecules of Ca, Al, and Fe, which remain in the soil longer, offering additional nutrients for crop production. Chemical amendments were found to reduce soluble P in poultry litter (DeLuca and DeLuca, 1997). Sediments, aluminum oxide, polymers, and activated C are water treatment residuals. These residuals can be effective in reducing P runoff due to chemical properties, which absorb nutrients such as P (DeLuca and DeLuca, 1997).

Phosphorus management may also be handled through practices that maximize crop P uptake and minimize P inputs from commercial fertilizers through the use of best management practices (Sims et al., 1998). Currently, the most utilized method of P removal is through fertilization of farm crop acreage with animal wastes. However, as total farm acreage decreases relative to animal numbers, the potential for excess nutrients remaining on the land to either runoff, leach, or volatilize increases. Therefore, proper agricultural management has the potential to reduce the amount of nutrients entering major watersheds throughout the world (Sharpley et al., 1998).

Role of Animal Agriculture

Intensification of Animal Agriculture

With an increase in livestock numbers per operation comes the inevitable increases in animal wastes (Sharpley et al., 1998). Development of nutrient budgets can help farmers plan how to maximize use of dairy wastes as fertilizer. When developing nutrient budgets, a total systems approach may be applied to encourage sustainability of dairy farming. A sustainable farm is considered to be one that has its nutrients balanced in such a way that soils are neither depleted nor excessively fertilized (Van Horn et al., 1996). There are several important issues to consider when developing a total systems approach to managing animal wastes. These include human and animal health, odor control, fly control, manure processing for export, and determining how broad environmental regulations and enforcement are going to affect the dairy farming industry as a whole (Grusenmeyer and Cramer, 1997).

Before World War II, cows typically consumed forages that were grown on the same farm, and were fertilized with dairy wastes. During that time, there were few or no additional nutrient sources applied to fields. Once commercial fertilizers were introduced, environmental problems began to increase. As farmers saw an increase in yields due to fertilizers, they continued to use them in addition to using manure.

With continued application of manure nutrients, fields begin to accumulate nutrients such as P and K. Other nutrients such as N would volatilize due to either over-application of commercial fertilizers and manure or through chemical reactions (Van Horn, 1994). In addition, intensive livestock farming [1000 animal units/farm = 1000 beef cattle, 700 dairy cows, or 2500 sows (Parry, 1998)] practices have increased, leading to increased manure spreading (Sharpley et al., 1998). For instance, in 1959, over 62% of the nation's dairy cows were milked on farms of 30 cows or less (Lanyon, 1992). In 1987, this percentage had dropped to only 8% of the dairy cattle being milked on 30-cow or less dairies. Meanwhile, the dairies milking 100 cows or more increased to 42% from only 1% during the same time frame. Intensification of livestock per farm has the potential to increase nutrient losses as well as the complexity of farm nutrient management (Bacon et al., 1990).

To illustrate these points, a New York state study analyzed the effects of a dairy farming operation on water quality and soil nutrient analysis from 1979 to 1994. Throughout this time frame, imported N increased, total milk production increased, soil P increased from 6 to 24 kg/ha, and the mean NO_3 levels of five wells located in cornfields throughout the dairy increased from 3.3 to 7.0 mg/kg of NO_3 (Wang et al., 1999). These results suggest that an increasing N balance on dairy farms could result in increased well water NO_3 levels, and lead to methemoglobinemia or other serious health threats.

Nutrient Budgets on Farms

One way to remain sustainable in dairy farming and to monitor nutrient use is through the use of whole-farm nutrient budgets (Kohn et al., 1996). Through the use of nutrient budgeting, studies have shown that there is more N and P being imported on farms than is being taken off the farm (Frink, 1969;

Bacon et al., 1990; Korevaar, 1992; Lanyon, 1992; Mandersloot et al., 1995; Chase, 1999; Wang et al., 1999). Nutrient budgeting spreadsheets provide dairies with information as to where changes need to take place on the farm (Van Horn et al., 1996).

In order to develop a whole-farm nutrient budget using a total systems approach, several issues need to be examined before inputs or outputs are measured. For example, types of nutrients excreted by food animals must be determined. Similarly, crops used to feed farm animals must be considered along with potential crop nutrient removal from the soil. Likewise, losses of nutrients within the manure handling, storage, and removal systems must be considered. All of these variables need to be discussed before any inputs or outputs are determined or measured for a whole-farm nutrient budget (Bacon et al., 1990; Lanyon, 1992; Van Horn et al., 1996; Wang et al., 1999).

Inputs and outputs to be measured in a nutrient budget spreadsheet include number of animals on the farm, dry matter intake (DMI), nutrient composition of crops, milk production, composition of milk, and analysis of nutrients contained in manure (Van Horn et al., 1996). A nutrient budget should incorporate feed, fertilizer, N fixation, and rainfall as farm inputs, with milk nutrient composition, animals sold, and volatilization as outputs (Frink, 1969). Others used fertilizers, concentrates, purchased forages, milk products, purchased animals, N fixation, bedding, and detergents for farm nutrient inputs, and outputs consisted of milk, sold animals, and sold forages (Korevaar, 1992). Another nutrient budget consisted of fertilizer and concentrates as inputs, and milk and sold animals as outputs (Van Keulen, 1982). All studies were designed according to the parameters decided by each researcher. In many farming situations, nutrient imports exceed exports by 3 to 8 fold (Klausner et al., 1998).

Farmers must consider that even though N, P, and K content of fertilizer are reported as 10-10-10, 12-12-12, 6-24-24, etc., this does not mean that there is 10% pure P and 10% pure K in the fertilizer. Phosphorus is incorporated into fertilizers in the form of P_2O_5; therefore, of the 10% P in the example combination, only 43.6% of the P can be considered. Likewise, K is in the form of K_2O; therefore, of the 10% K in the combination, only 83% of the K can be considered. Thus, the actual ratio of nutrients of 10-10-10 fertilizer is 10-4.36-8.3 (Van Horn et al., 1997).

One study determined nutrient flows into, within, and out of a dairy operation in New York utilizing nutrient budgets (Hutson et al., 1998). Most of the N that comes onto farms is in the form of purchased feeds, fertilizer, and N fixation by crops. Most nutrients left the farm in the form of milk, crops, and animals. These accounted for 30 to 40% of the total nutrient inflows in this study. Improvements in feeding practices, crop efficiency, management style, and a reduction in purchased fertilizer caused marginal improvements in nutrient balance on the study farm (Hutson et al., 1998). A total of 72% of N inflows and 57% of P inflows were not accounted for in milk, crops, or animals sold in this study (Hutson et al., 1998). Nitrogen was in excess by 10,900 kg/yr and P was in excess by 5,409 kg/yr (Hutson et al., 1998). Nitrogen excess was 17% of inflows and P was 57% of inflows (Hutson et al., 1998).

There are several ways to increase nutrient efficiencies. These include feeding more farm-grown forages to animals, decreasing volatilization of N from storage to increase the amount of N that can be used on the fields, and increasing the proportion of total N intake that is converted to N in milk (Aarts et al., 1992; Hart et al., 1997; Hutson et al., 1998). Reducing amounts of purchased feeds decreased the percentage excess N on the farm from 72 to 67% (Hutson et al., 1998). Removing all purchased fertilizers reduced this to 65%, and increasing animal efficiency resulted in a 64% excess of N inflows. It is obvious from these results that minor management changes led to a decrease in excess N and P. However, there was still a net excess of nutrients remaining on the research farm.

Only a small fraction of all N consumed by animals is utilized. As much as 80% of N consumed is excreted in urine and feces (Aarts et al., 1992). Dairy animals convert N to meat and milk at a maximum level of 43% of the total N consumed (Aarts et al., 1992). Nitrogen utilization averages between 15 and 25% (Aarts et al., 1992). Since fecal N excretion is relatively constant (.35 to .55 kg of N/d), most of the surplus N in the diets is excreted through urine (Aarts et al., 1992; Van Horn et al., 1997; Wilkerson et al., 1997).

There are many ways in which dairy farms can increase their efficiency in nutrient management. However, it is most important that dairy farmers realize that their management decisions impact more than just their individual farms. Once realized, dairy farmers could then start making improvements in farm nutrient management.

Regulations

General Information

After an increased occurrence of eutrophication across the country, regional and federal governments decided that nutrients needed to be monitored and controlled (Daniel et al., 1998). As an example, The Chesapeake Bay Program reported that 61% of nutrients entering the Bay could be attributed to agricultural nonpoint sources. This has led to more stringent water quality regulations. As production agriculture has moved toward more intensive farming methods, permits are required for farm wastewater and runoff. Collaborative efforts between the federal, state, and regional lawmakers along with farmers and universities will become increasingly important as the laws and policies guiding intensive agriculture are reviewed (Parry, 1998).

Some nutrients can be recovered by simple means, but ever-increasing governmental regulations are forcing more expensive nutrient handling plans (Aarts et al., 1992). There is a trend in several states to change manure spreading policies over to N and P standards, or to a P based policy (Schmitt et al., 1999). The Dutch government requires the use of low emission slurry application such as liquid manure injection or dilution, adding nitric acid to slurries, and covered lagoons to reduce nutrient loss (Aarts et al., 1992; Mandersloot et al., 1995).

Acts and Plans

Regulations are in place that limits the amount of dairy waste being spread (Hart et al., 1997). These regulations establish the foundation behind P based nutrient management plans, which call for utilizing fertilizer and waste to meet P demands of farm crops (Sharpley et al., 1998).

Phosphorus based nutrient management plans were developed by the federal government and are enforced through the Environmental Protection Agency (Parry, 1998). Other acts passed by the government to regulate P include the Clean Water Act, Coastal Zone Act, Reauthorization Amendment, and Total Maximum Daily Loads (TMDL) (Parry, 1998). Total Maximum Daily Loads indicate how much of a certain nutrient that a body of water can utilize on a daily basis (Parry, 1998). Total Maximum Daily Loads can ultimately be used to help control point source and nonpoint sources of pollution (Parry, 1998). However, the Clean Water Act does not allow the EPA any regulatory action against nonpoint sources of pollution. Additionally, groundwater is not covered under the Clean Water Act, only surface waters (Parry, 1998). As of 1998, 21 states had no P water quality standards (Parry, 1998); however, twelve states had narrative criteria for P, which helps control eutrophication. Currently, only Florida uses the EPA marine and estuary criteria of .10 mg of P per L or less (Parry, 1998).

As of April 14, 2003, new National Pollutant Discharge Elimination System (NPDES) guidelines will take effect for CAFOs (Federal Register, 2003). This new ruling was developed by the EPA in an attempt to encourage and ensure proper manure management by CAFOs in hopes of protecting our nation’s water supply. One of the main attributes of the new ruling is for all of the estimated 15,500 CAFOs, which are producing 300 million tons of manure annually, to develop and implement nutrient management plans as a condition for obtaining a NPDES permit (Federal Register, 2003).

Nutrient management plans are required by the EPA in the new ruling; the EPA does not require them to be developed by certified experts (Federal Register, 2003). Therefore, anyone who is knowledgeable in “soil science and soil fertility, nutrient application and management, crop production, soil and manure testing and results interpretation, fertilizer materials and their characteristics, BMPs for management of nutrients and water, and applicable laws and regulations” could potentially develop a farm nutrient management plan (Federal Register, 2003). Each CAFO nutrient management plan must ensure and maintain adequate storage of animal waste and wastewater from the facility, manage mortalities appropriately so that none are disposed in waste holding facilities, divert clean water from facilities, maintain chemicals and contaminants so that none contact manure or wastewater, implement conservation practices, test manure and wastewaters to ensure appropriate crop utilization, and maintain adequate records to monitor previously mentioned elements of the farm nutrient management plan (Federal Register, 2003).

The new rules also state that if CAFO facilities are currently in existence, the standard prohibition of manure and wastewater discharge is in place except in the event of a 25-year, 24-hour rainfall event (Federal Register, 2003). However, new swine, veal, and poultry CAFOs will have a zero discharge standard regardless of the size of storm event, which is much more stringent (Federal Register, 2003).

Large CAFOs (1000 AU plus) are required under the new law to implement several BMPs (Federal Register, 2003). For instance, large CAFOs must perform weekly inspections of all waste and water holding facilities as well as clean water diversions around the facilities (Federal Register, 2003). The BMPs require daily inspections of all water lines including drinking water or cooling water lines (Federal Register, 2003). Depth markers are required in all waste and/or water holding facilities to indicate minimum capacity needed for a 25-year, 24-hour rainfall event (Federal Register, 2003). Any daily or weekly problems arising from inspections are required to be corrected as soon as possible. Mortalities are to be disposed of in a manner in which wastewater will not come in contact with carcasses. Finally, on-site copies of records from the preceding BMPs must be kept for a minimum of 5 years of their creation (Federal Register, 2003).

Lastly, the new rules require CAFOs to submit annual reports to the EPA (Federal Register, 2003). These reports include number and type of animals housed, estimates of manure amounts for the previous 12 months, estimates of transferal amounts of manure to other persons, total land acreage for nutrient management plan, acreage of land used to distribute waste, summary and volume of waste removal from CAFO, and a statement indicating that the nutrient management plan for the CAFO was or was not designed by a certified planner (Federal Register, 2003). Interestingly, previously mentioned reports will be available to the public so that concerned citizens may offer inquires to state regulatory offices if there are any supposed violations.

The EPA has given implementation and regulatory responsibilities to individual states (Federal Register, 2003). Currently, there are 45 states and 1 territory that have NPDES permitting authority (Federal Register, 2003). The EPA will govern the remaining states who have no regulatory board. The responsibilities given to the states and territory also direct each state and territory to keep current with NPDES rules and changes.

According to the EPA, the new rules were established due to a trend indicating fewer but larger CAFOs depositing excess waste on smaller land areas. Excess waste was defined as “manure nutrient production that exceeds the capacity of the crop to assimilate the nutrients” (Federal Register, 2003). Large CAFOs attributed the largest share of excess nutrients in 1997 (Federal Register, 2003). Crops grown on the CAFO acreage cannot utilize the majority of N and P in manure produced by the CAFOs. The EPA estimates that 60% of the N and 70% of the P must be removed from these farms in order to prevent possible environmental dangers (Federal Register, 2003). In addition, the Southeast and Mid-Atlantic states have shown the largest increases in excess nutrients between 1982 and 1997 (Federal Register, 2003). The EPA has specifically listed Virginia as an area of “particular concern” for excess manure nutrients. Along with Virginia, Maryland, Delaware, and Pennsylvania were also listed (Federal Register, 2003). All of these states are tributaries to the Chesapeake Bay Watershed.

With the new rulings in place, the EPA has estimated annual environmental benefits associated with these new rules. Major benefits include but are not limited to increased recreational use of freshwater rivers, streams, and lakes; reductions in fish kills; improved shellfish harvest; reducing nitrate contamination in private wells; reducing eutrophication; decrease public water treatment; and improved soil properties (Federal Register, 2003). As far as large CAFOs, better management of nutrients can reduce nutrient loss by 24% or 341 million kg (Federal Register, 2003). Medium CAFOs could expect to reduce nutrient loss by 17% or 24.2 million kg (Federal Register, 2003). No designation of nutrient loss (N, P, or K) was given. Total dollars associated with these benefits range from $204.1 million to $355 million annually (Federal Register, 2003).

The EPA has also budgeted an annual cost to implement and maintain these rules. Costs are broken down by animal sector and CAFO size. The annual cost is estimated to be $326 million dispersed among all animal sector CAFOs (Federal Register, 2003). This cost estimate is more than half of the expected benefits of the new ruling, and the majority of these costs are being paid by those not receiving the benefits listed earlier. The dairy sector is expected to pay 46% of the costs associated with these new rules (Federal Register, 2003). Of the 1,450 large dairy CAFOs, each one would have to pay an estimated $88,414 per year to cover the dairy portion of the total bill (Federal Register, 2003). Each of the 1,949 medium dairy CAFOs would incur a bill of $11,288 per year (Federal Register, 2003). When all cattle industries (fed cattle, veal, heifer, dairy) are factored, the cattle sector will pay more than 75% of the total costs of the new rules (Federal Register, 2003).

Realizing the economic burden to individual sectors and individual CAFOs, EPA characterizes CAFOs into three distinct economic areas. These areas include an “Affordable, Moderate, and Stress” characterization (Federal Register, 2003). Expectedly, the Affordable and Moderate classification indicates those CAFOs that could incur these costs with little or no economic impact (Federal Register, 2003). However, a Stress classification indicates a CAFO that is “vulnerable to facility closure (Federal Register, 2003).” All large dairy CAFOs where classified as Affordable or Moderate. Of the 242 large heifer CAFOs, 22 were classified as Stressed, which could have a trickle down effect of decreasing dairy heifer numbers and increasing dairy heifer prices (Federal Register, 2003).

Farm Management

Cropping Strategies

A trend to increase milk production has yielded the need for better crop production. In turn, this has led to large amounts of N being applied to increase crop yields. However, crops are beginning to retain much of the excess N from the soil, and animals are in turn consuming larger than expected quantities of N (Hof et al., 1997). For this reason, farmers should be knowledgeable about crop nutrient utilization, amount of manure provided to crops, nutrient content of manure, and future requirements of crops (Lanyon, 1994). This combined information influences optimal growing conditions in such a way that plants can efficiently use soil nutrients (Kohn, 1996).

Much research has been dedicated to increasing nutrient availability to crops and applying dairy manure in ways to minimize nutrient loss. Timing of manure application to meet farm crop needs is important to achieve maximal nutrient uptake by plants (Aarts et al., 1992; Lanyon, 1994). Also, crop selection can increase farm efficiency of nutrient utilization by 59%. Likewise, improved manure management can increase nutrient efficiency by 13% (Kohn et al., 1997).

Many types of research projects, crop genetic modifications, management decisions, and specialized tests have been examined to increase understanding of crop nutrient uptake. During research performed at Tifton, Georgia, a three-crop rotation was initiated, which included rye, bermudagrass, and corn silage (Van Horn et al., 1996). Research indicated that, due to increased quantities of N, more manure irrigated on test plots resulted in increased plant recycling and N utilization (Van Horn et al., 1996). Data from the same research suggested that P was recycled in increasing amounts through plants as the amount of liquid manure applied increased, and different crops within a rotation may remove more nutrients than other rotations. However, researchers suggested that increases in P uptake were due to increased crop yield from adequate moisture and other nutrients (Van Horn et al., 1996).

Even though forage crops, such as corn, can utilize large quantities of N, less than 25% of the P that is applied is utilized by plants (Hart et al., 1997). As a result, there is an accumulation of P in the soil (Hart et al., 1997). Because P requirements of plants are lower than requirements for N, approximately twice the land is needed to dispose of manure to meet plant requirements for P compared with N (Lanyon, 1994; Van Horn et al., 1996). The best case scenario would be having enough land to spread manure based on P requirements of plants, and purchase supplemental N (Van Horn et al., 1997). However within the Shenandoah Valley of Virginia and other areas of intensive animal agriculture, nutrient excesses exist, and exportation of manure from the farm is often needed.

Understanding a crop's nutrient needs will help determine upon which soils the crop should be planted (Hart et al., 1997). For instance, alfalfa will remove more P and K than grasses. In addition, alfalfa is a legume that fixes N. Therefore, a reduction in or no manure spreading may be necessary if the alfalfa was planted in soil that had been fertilized with manure in past years (Hart et al., 1997).

A special test has been developed to determine if soil in which corn is planted has enough N to meet plant needs (Hart et al., 1997). Pre-silk N test (PSNT) is administered before the critical growing stage of the corn plant. The critical growing stage of a corn plant is defined between six leaves until silking. Core soil samples are taken, mixed together, and analyzed for nitrate (NO_3). If NO_3 content is greater than 20 ppm, there is sufficient N for the critical stage of growth for the eastern United States (Hart et al., 1997).

Other tests can be administered after corn plants have been harvested to determine if N levels are adequate for maximal corn production. The corn stalk NO_3 test can be performed on eight stalks per field. Nitrates accumulate in the lower portions of corn stalks late in the growing season, and if NO_3 levels from stalks are between 3500 and 5000 ppm, N content in soil was adequate for maximum yields (Hart et al., 1997). Afterwards, PSNT can be measured again.

If there is greater than 15 ppm of NO_3 in the remaining top 12 inches of soil, there was too much N supplied to the crop (Hart et al., 1997). After corn harvest, farmers should plant cover crops to reduce NO_3 left in the soil (Frink, 1969; Aarts et al., 1992; Van Horn et al., 1997).

Another option is to reduce the P content of manure. Low phytic acid corn, which is a genetic modification within the germ, was shown to reduce the phytic acid levels in corn by as much as 65% (Ertl et al., 1998). This modification allows more P to be absorbed for use by monogastric species and less total P deposited in manure. Low phytic acid corn did not express any adverse agronomic traits compared with regular corn; however, yield results were slightly lower for 8 out of 14 trials (Ertl et al., 1998).

Other research has indicated that stocking rates of 1.5 to 2 animal units/ha are needed to provide manure nutrients needed to grow most crops (based on N needs) without addition of commercial fertilizer (Van Horn et al., 1996; Hart et al., 1997). However, it is estimated that a cow will need .81 to 1.21 ha on which to spread individually produced manure to fully utilize unabsorbed P (Satter and Wu, 1999).

Another possible crop strategy to indirectly encourage manure management is to limit grazing to the daytime, which helps reduce the number of urine and fecal deposits so that there is less NO_3 leaching into ground water or running off (Aarts et al., 1992; Mandersloot et al., 1995). Assuming that cattle are brought in at night and housed in barns with concrete floors, there is potential to significantly reduce the amount of urine patches that could leach, as urine would not have direct access to soil (Mandersloot et al., 1995). However, if cattle are allowed to graze on pasture during daylight, there is potential to deposit more N and P than if the cows are allowed to pasture just at night. General grazing activity could lead to increased numbers of urine and fecal deposits.

Lastly, with weather patterns that are different year after year, following nutrient management plans may still result in NO_3 leaching into groundwater. For instance, if a farmer expects extended periods (days, weeks, months) of dry weather, he is likely to allow this expectation to influence his manure spreading policies. However, if this same farmer spreads manure as he has in previous years, and over the summer and fall there are abnormally large amounts of rainfall, this could contribute to increased nitrate leaching or runoff problems. Therefore, it is important that dairy farms closely monitor crop production and manure management on a yearly basis (Lanyon, 1994).

Manure Management

For dairy farming to continue to be a viable source of income, a total systems approach to manure management will have to be followed. This approach reaches beyond ration balancing, cattle management practices, and manure handling techniques currently used.

In general, the most accepted means of manure removal is to recycle nutrients back to the soil so that subsequent forages can utilize these nutrients (Van Horn et al., 1996). If sufficient land exists, manure should be spread based on P requirements of crops to be grown, and supplemental N should be purchased and applied from off-farm sources. If land resources are not available, manure should be spread according to maximum N uptake by plants, and multiple cropping systems and irrigation systems should be incorporated to encourage additional uptake of N and P by all forages. If excess nutrients still exist, additional manure should be exported off farm (Van Horn et al., 1996). As an example, in the western U.S., several farmers have decided that instead of sending empty rail cars back to grain terminals, they return dry manure for spreading where there may be a need for cheap fertilizer (Daniel et al., 1998).

Other alternatives to removing nutrients off farm include application of manure on nearby farms, burning manure (which allows removal of ash), and sedimentation and/or composting (Van Horn et al., 1996). To illustrate the first point, typically manure is spread on the closest fields to the farm, generally within a 20-km radius of the farm. To reduce the impact of overloading the soil with manure nutrients, manure must be hauled longer distances to areas deficient in nutrients (Sharpley et al., 1998; Satter and Wu, 1999).

To illustrate the advantages of burning manure, the United Kingdom has established facilities to turn poultry manure into electricity. Manure is burned to boil water for the production of steam to power electric generators. This system has netted an internal rate of return between 23 and 42% (Van Horn et al., 1996; DeLuca and DeLuca, 1997).

The most common and accepted method of manure removal is through composting manure and subsequently selling compost as fertilizer to other farms or individuals (DeLuca and DeLuca, 1997; Grusenmeyer and Cramer, 1997). Composting combines fecal wastes from confined animals and crop residues to provide a fertilizer that has stabilized nutrients, killed pathogens and weed seeds, and reduced odor. Spreading composted animal wastes improves soil quality because N and P mineralize gradually in composted fertilizers, allowing for extended nutrient availability. Also, composting helps to remove solid wastes from concentrated animal areas and fertilize cropland without having to purchase nutrients such as N, P, or K (DeLuca and DeLuca, 1997). However, even though composting is a logical alternative to spreading manure, it is relatively costly, labor intensive, and some N is volatilized during processing (Van Horn et al., 1996).

Most over-application of manure waste can be linked back to a simple lack of N crediting for applied manure. For example, in one study, several farms spreading poultry waste were receiving yearly soil test that indicated an excess of N by 22.73 kg/ha. Other farms were shown to have as much as 27.27 kg/ha in excess N (Schmitt et al., 1999). Manure crediting includes taking manure samples and measuring levels of nutrients in manure being spread, having soil tests performed on a regular basis, and calibrating the manure spreader (Schmitt et al., 1999).

To derive an accurate measure of total N, P, and K in manure, dairy farmers must calculate composition of the manure, the weight of the loads, the number of loads hauled to the field (Van Horn et al., 1997). Composition of manure is a key element to remember since 90% of excreted P can be recovered in manure, and 80 to 90% of excreted K can be recovered in manure (Frink, 1969; Van Horn et al., 1997). In contrast, as much as 80% of N can be volatilized before being spread on fields (Bulley and Holbek, 1982).

It is important to take a well mixed sample of manure because N content varies with animal breed and species, diet, manure handling systems, methods of storage, spreading and local environmental constraints (Bulley and Holbek, 1982). When taking samples of manure from storage, it is important to sample contents of the pit at different depths and several locations around the pit. Accurate measurements of manure waste before spreading may decrease potential for surface and groundwater pollution.

Recently, several products have entered the market that could potentially be used along with lab results to accurately predict manure nutrient content (Van Kessel et al., 1999). These tools include hydrometers, electrical conductivity tests, ammonia electrodes, reflectometers, Agros N Meters, and Quantofix-N-Volumeters (Van Kessel et al., 1999). All tests proved more accurate when used on slurries than dry solids (Van Kessel et al., 1999). Of these products, only hydrometers determine total N and P content of manure samples. The others determine ammonium N, and only two of the tests measure K in addition to ammonium N. These two products were the conductivity meter and the conductivity pen (Van Kessel et al., 1999). All tests had high reliability ratings and repeatabilities. However, a major source of variation was individual farms and farming situations (Van Kessel et al., 1999).

Van Kessel et al. (1999) also determined ease of operation for each test. For this, researchers asked a high school student to use each test to determine nutrient results of six different types of slurries. Instructions for use of each test were given and all students were allowed to practice the tests. Nutrient content and dry matter were determined for each sample. The student's results indicated that all tests were easy to use as an R^2 value of better than .971 was obtained for each test. However, hydrometers proved to be the easiest to use and cheapest of all tools at $40. The most expensive was the ammonia electrode and meter at $2000 (Van Kessel et al., 1999).

Management practices to reduce volatilization include removal of urine and feces as quickly as possible from barn floors, covering slurry pits, and applying manure using injection techniques. Applying manure during growing seasons instead of dormant seasons also helps reduce volatilization. Covering slurries could reduce ammonia emissions by 50 to 90% (Korevaar, 1992).

Masters (1993) developed a low cost treatment system for reducing dairy waste, which used three stages to remove nutrients and return dairy waste to land as a valuable fertilizer. The stages included a sump (i.e., lagoon) for anaerobic digestion, an aerobic filter strip, and irrigation of cropland with dairy wastes (Masters, 1993). The sump, which was developed to hold waste from 100 cows for 20-d, held solid matter from farms and allowed for liquid to undergo an anaerobic digestion of organic matter and some nutrients. During this 20-d period, up to 50% of P in dairy waste settled to the bottom and was trapped in sludge. Most sumps used measured 2.5 m deep and covered an area of 100 m^2.

Filter strips, encompassing 20 ha, were the second phase of the system, in which nutrient absorbing plants were used to help remove nutrients. Plants consisted of salt-water couch, kikuya, and other native plants of the area. Filter strips were used so that native plants could utilize some of the nutrients flowing out of the sump before being spread on cropland, thus reducing the amount of nutrients applied. The last step was to irrigate remaining water over crops that could utilize remaining nutrients. Total cost of the system averaged $1600 so that dairy farmers would be encouraged to experiment with filtration systems. Of course larger sumps, filtration strips, and irrigation mechanisms add cost to the entire system, and eventually the P that settles in sludge must be removed and disposed in some way (Masters, 1993).

Computer software can help a farmer determine where, when, and how much manure to spread. Programs like Manure Application Planner (MAP) allow farmers to plan the most effective and feasible way to spread manure to reduce possibility of nutrient runoff or leaching. As noted by Schmitt et al. (1997), these programs attempt to solve some of the more common problems associated with other manure management tools, such as timely hand written calculations associated with human error, over-application of nutrients, and below average economic returns.

Animal Nutrition

One of the most economical and practical methods to achieve farm nutrient balance is to manage animal nutrition. As the numbers of cows per farm have increased, available land for crops has decreased, leading to a reliance on off-farm feedstuffs. This brings additional nutrients onto the farm with less land mass on which to spread dairy wastes, which leads to an accumulation of nutrients in the soil, leaching, or run off (Lanyon, 1994). Emphasis must be placed on managing and reducing nutrients being fed to dairy animals (Kohn, 1996; Jonker, 1998).

As producers try to increase production, better feeding practices need to be implemented to reduce inefficiencies in protein and P usage (Grusenmeyer and Cramer, 1997). Through the use of best management practices, researchers estimate that it is possible to reduce N surplus by 25 to 50% in 2 yr (Korevaar, 1992). One of the easiest ways to reduce on farm surpluses of nutrients is to remove excess nutrients present in the ration (Van Horn et al., 1996).

As computer generated dairy rations have become widely accepted, computer ration balancing programs may play an important role in nutrient utilization. When using these programs, one particular way in which to minimize feeds brought onto farms is to feed as much on farm forage and grain as possible to limit purchased feeds, placing caps on dietary percent P in least cost linear programs, and offering no economic benefit in linear programs for using high P feedstuffs if P is not needed. These practices can reduce nutrients brought onto dairy farms since purchased feeds tend to be the main stimulus for on farm accumulation of nutrients (Frink, 1969; Aarts et al., 1992; Hart et al., 1997).

Accurate nutrient intake information is the single most important item to predict nutrient excretion (Van Horn et al., 1996). Since nutrient intake is essentially determined by dry matter intake (DMI), there has been an enormous amount of research dedicated to developing optimum DMI equations. In a study performed by Roseler et al. (1997), large variations between equations were noted. Most variation between DMI equations was attributed to farm management and environmental conditions. Variation in DMI was also noticed when researchers tried to predict DMI for high producing cows, cows that were given bST treatments, and in cows of different parity (Roseler et al., 1997).

Of six prediction equations evaluated, the modified Nutrient Requirement Council (1989) equation tended to be most accurate (Roseler et al., 1997). The equation, DMI = (-0.293 + 0.372 x fat corrected milk in kg/d + 0.0968 x body weight $^{0.75}$ in kg) was used by Roseler et al. (1997) to predict nutrient requirement for nutrient balances. In order to predict the DMI of a cow or group of cows, many factors need to be considered. There is no one perfect prediction equation for DMI due to differences in environment, management practices, herd differences, etc. (Roseler et al., 1997).

Development of lead factors has influenced nutrient intake according to grouping strategies (Stallings and McGilliard, 1984). Lead factors have been developed to overfeed dairy animals in a controlled fashion so that a certain percentage of the herd is receiving adequate to more than adequate nutrition in an effort to increase milk production (Stallings and McGilliard, 1984). Stallings and McGilliard (1994) proposed a lead factor corresponding to ((milk yield of the 83rd percentile cow)/mean milk yield). In feeding cattle according to lead factors that meet or exceed nutritional requirements for the 83rd cow, farmers are ultimately trying to provide sufficient nutrition to their high-producing animals

(Stallings and McGilliard, 1984). Grouping strategies will help target different production groups and these groups can be fed to closely match their nutrient requirements instead of overfeeding them, causing increased excretion or underfeeding them leading to decreases in milk production (Stallings and McGilliard, 1984; Jonker, 1999).

Soil Accumulation

Due to reduced commercial fertilizer costs as compared to pre-WWII fertilizer costs and importation of concentrates onto farms, nutrients have started to accumulate in the soil (Kohn, 1996). Soil binding of ions affects the amount of N and P that can be applied (Van Horn et al., 1996). As an illustration, a 10,000-head feedlot located on soil that requires P according to plants grown with 250 ha set aside for grain production and manure application should have an estimated sustainability of 132 yr before P becomes a limiting nutrient. In contrast, if the same 10,000-head feedlot locates on soil that has a high P content (440 kg/ha) with 250 ha set aside for crop production and manure spreading and a ration with 30% more P than needed, it would only have a maximum sustainability of .6 yr (Van Horn et al., 1996). It is imperative to monitor soil to determine what nutrients are needed. Soil tests need to be performed on a yearly basis to aid in measuring nutrient balance (Daniel et al., 1998).

Nutrition to Reduce N Losses

Rumen Degradable Protein/Rumen Undegradable Protein

Dairy nutrition revolves around the management of protein fractions in rations for maximum milk production. Protein fractions consist of rumen degradable protein (RDP) and rumen undegradable protein (RUP). Rumen degradable protein is that portion of protein that is broken down in the rumen. Rumen undegradable protein escapes degradation in the rumen and can be utilized in the intestine of the animal. If there is too little RDP, rumen bacteria may not grow optimally and fiber digestion and intake may be impaired. On the other hand, there needs to be enough protein that bypasses the rumen, RUP, to be absorbed in the small intestine to maximize milk yields.

Excessive RDP or RUP can decrease N utilization and microbial protein production. Therefore, if rumen outflow is too fast, there is potential for increasing N excretion. If rations are properly balanced according to protein fractions, N excretion may be reduced by 15% compared with cows fed diets balanced for crude protein alone (Van Horn, 1994). Researchers suggest that in an effort to minimize N losses, the ratio of RDP to RUP must be one or slightly higher (Schepers and Meijer, 1998).

Milk Urea Nitrogen

Excess amino acids and peptides are deaminated in the liver and the N is converted to ammonia. Because ammonia is detrimental to animals, the liver then converts ammonia to urea. Urea is then carried throughout the body by the blood (BUN). Through simple diffusion, urea is moved into the mammary gland

and kidneys. From these organs, urea is excreted in milk as MUN, which is 2.5 to 3% of total milk N, or through urination as urinary N (Jonker, 1998). Because BUN diffuses easily into mammary tissue and the kidneys, a strong correlation exists between BUN and MUN, and BUN and urinary N (Broderick and Clayton, 1997; Larson, 1997; Jonker, 1998; Schepers and Meijer, 1998; Jonker, 1999; Melendez et al., 2000). Expectedly, as milk production increases, so will the MUN and N excretion because of increased N intake if the ration is not properly balanced to meet the animal's nutrient requirements. In one study, overfeeding N by 10% resulted in a 13% increase in MUN (Jonker, 1999).

Milk urea N and BUN are good predictors of protein efficiencies in dairy rations if energy levels of the ration are adequate (Jones et al., 1982; Gustafsson and Palmquist, 1993; Broderick and Clayton, 1997; Hof et al., 1997; Jonker, 1998; Chase, 1999; Jenkins et al., 1999; Jonker, 1999; Godden et al., 2000). The normal range for MUN is between 10 and 16 mg/dl, with anything outside this range either being high or low (Jones et al., 1982; Jonker, 1998, 1999). This range gives dairy farmers a tool to determine if animals are receiving too much, adequate, or not enough protein. When MUN is used to evaluate protein content of rations, milk samples need to be taken from the entire herd if possible. A representative sample can be obtained from four to ten cows per feeding group (Broderick and Clayton, 1997; Hof et al., 1997).

Bulk tank samples can be taken, but analysis is not as conclusive as individual cow samples from an entire group (Hof et al., 1997). This is due, in part, to the fact that some herds have milk shipments on an every other day basis and different rations could have been fed. Milk samples taken from a composite sample more closely match that of the serum urea concentrations than do quarter stripping samples (Godden et al., 2000).

Milk urea N analyses differ between a.m. and p.m. milkings (Gustafsson and Palmquist, 1993). MUN levels are lower for samples taken in the morning than samples taken in the evening. Therefore, milk samples analyzed for MUN should be consistently taken either during morning or evening milkings, but not alternating (Broderick and Clayton, 1997). This indicates a diurnal variation between BUN and MUN. This diurnal variation could be a major source of error when using MUN as a nutritional indicator (Gustafsson and Palmquist, 1993; Schepers and Meijer, 1998).

Excessive crude protein in diets with adequate energy levels is most often the cause of increased MUN values (Broderick and Clayton, 1997; Larson, 1997; Jonker, 1999). However, there are other causes of elevated MUN values. For instance, time of feeding influences MUN levels (Gustafsson and Palmquist, 1993). Blood urea N levels are highest approximately 3 h after cattle have consumed the diet (Broderick and Clayton, 1997). Other work has shown MUN to be highest 2 h after feeding followed by a gradual decrease in MUN 6 h later. Increases in both studies were related to an increase in rumen ammonia (Rodriquez et al., 1997; Schepers and Meijer, 1998).

First lactation cows have higher MUN values than mature cows (Jonker, 1998). If cows are grouped by lactation, these younger cows often receive a ration that is higher in crude protein to encourage growth. However, if not managed appropriately, the crude protein in this ration could be too high, which could increase MUN (Jonker, 1998). No effect was observed on MUN due to body weight (Broderick and Clayton, 1997; Jonker, 1998, 1999). In other studies, however, MUN was positively related to body weight (Broderick and Clayton, 1997). Larger animals tended to have greater renal clearance rates, resulting in differences in MUN values due to greater blood volume (Jonker, 1999; Rodriquez et al., 1997). A breed effect has been noticed concerning MUN. Holstein cattle tended to have higher MUN values than Jersey cattle (Rodriquez et al., 1997). This breed effect is likely due to the difference in body weight.

Milk urea N was found to be sensitive to individual dairy feeding strategies and milk production (Jonker, 1999). Other studies have found negative relationships between MUN and milk yield, fat yield, crude protein per unit of net energy for lactation, and net energy for lactation intake (Broderick and Clayton, 1997).

Elevated MUN values need to be analyzed to determine the cause of the increase. Anything that could cause a decrease in milk production could cause an increase in MUN values (Jonker, 1998, 1999; Schepers and Meijer, 1998). Within a lactation, peak MUN concentration occurs at the eleventh week of lactation (Jonker, 1999).

Milk urea N concentration decreased with ionophore feeding (Erasmus et al., 1999). With the feeding of ionophores, amino acid deamination is significantly reduced, which reduces ammonia production (Erasmus et al., 1999). Overall, lasalocid decreased DMI and MUN, while increasing body condition score and feed efficiency. Milk urea N was closely correlated with dietary RDP content (Schepers and Meijer, 1998). Changing RUP amount in rations did not influence plasma urea N or MUN (Rodriquez et al., 1997). Improved protein utilization reduces the amount of ammonia produced to be excreted as urea either through milk or urine.

Some studies have indicated that MUN levels above 21 mg/dl could be associated with decreased pregnancies in early gestation (Larson, 1997; Erasmus et al., 1999). As MUN increases, BUN has also increased causing uterine pH to decrease several days after breeding. This low pH environment caused the destruction of the embryo, which indicated that high MUN could decrease fertilization rates before maternal recognition (Larson, 1997).

When focusing on management factors, lactation number and high MUN were negatively related to fertility (Larson, 1997). Conflicting data have found no association between MUN levels and possibility of increased open cows (Melendez et al., 2000). The same researchers observed a statistically significant relationship between high MUN values and pregnancy status of cows that were bred in different seasons of the year. Cows with high MUN bred in the summertime were eighteen times as likely to be open than cows with low MUN that were bred in the winter. A high MUN value for this study was classified as 17 to 25 mg/dl, with low MUN values between 6 and 16 mg/dl. Seasonal breeding effects might have worked synergistically with MUN values. In other words, cows are under heat stress during summer months, and increased MUN may decrease chances for embryonic survival or maternal recognition (Schepers and Meijer, 1998; Melendez et al., 2000). Variability in this study (Melendez et al., 2000) could have been reduced if the authors had taken MUN values on a monthly basis instead of a bimonthly basis.

Since the inception of MUN testing, researchers have derived many prediction equations from the MUN analysis. Urinary N can be predicted in g/d by multiplying 12.54 by the MUN value. A cow with a MUN test of 10 mg/dl of N is predicted to excrete 125.4 g/d of urinary N (Jonker, 1998, 1999). The 12.54 value is representative of 1254 L of blood that are cleared of urea per day (Jonker, 1998).

A prediction equation for MUN has been developed based on this. The equation is predicted urinary N / 12.54. Predicted urinary N is estimated as (predicted N intake x .83) – milk N – 97. Predicted N intake is calculated from the Nutrient Requirement Council (1989) (Jonker, 1999). Another prediction equation for MUN that uses BUN has been developed by other researchers (Broderick and Clayton, 1997). The equation is .620 x BUN + 4.75 (Broderick and Clayton, 1997). However, collecting blood samples is fairly difficult as sample collection is expensive, time consuming, and individuals need to be trained to take blood samples.

An assay has been developed that quickly determines the MUN for milking cows while in the parlor (Jenkins et al., 1999). This could lead to more rapid changes in rations, possibly resulting in more efficient protein utilization by the cow and less potential for environmental pollution or decreased reproductive efficiency due to an overfeeding of crude protein (Jenkins et al., 1999).

Newer infrared technologies are helping to reduce turnaround time and increase accuracy of MUN samples. Researchers have evaluated the Fossomatic 4000 Milk Analyzer and found that this new infrared technology compared favorably with standardized Eurochem Tests (Godden et al., 2000). Results of this study indicated that infrared technology could be used to measure MUN values compared with the accepted reference test. New technology was found to be faster and less expensive than typical MUN measuring techniques. The analytic precision was measured in cumulative variance and this was measured at 4.85%. Correlation between the Fossomatic 4000 Milk Analyzer and the Eurochem Test was .86 (Godden et al., 2000).

Other Measures for N

A reduction in total N intake could lead to improved reproductive efficiency, and reducing crude protein levels in diets could reduce feed costs (Dinn et al., 1998; Kalscheur et al., 1999). Monitoring forage crude protein levels and protein fractions on a regular basis can assist nutritional consultants in accurately developing dairy rations, reducing N amounts that may not be needed and likewise excreted, yet providing adequate crude protein for maximized milk production. Increasing DMI will, in turn, reduce the concentration of crude protein needed to produce the same amount of milk.

There is greater potential to reduce the amount of N accumulation on a farm through nutrition and crop selection than by composting, burning, etc. (Kohn, 1996). Management decisions and use of diet formulations that increased production by 50% increased N efficiency by 48% and reduced N losses by 36 to 40% (Paul et al., 1998). Improvements in rations have the biggest impact on N utilization and the potential to reduce N pollution to ground and surface waters, reduce total N in manure, and reduce ammonia losses to the atmosphere (Dinn et al., 1998; Paul et al., 1998).

Using rumen-protected amino acids (RPAA) may help increase the utilization of crude protein (Dinn et al., 1998). It is important to remember that a reduction in dietary crude protein may reduce milk yield; however, a reduction in crude protein with supplemental RPAA may keep milk protein content steady (Dinn et al., 1998). Using RPAA may provide the needed profile for absorption when less total N is fed, which could significantly reduce potential environmental threats from excessive N (Dinn et al., 1998).

Cows need appropriate amounts of protein before peak milk production, but after peaking, crude protein can be reduced because cows do not need as much protein because milk yield is not as high (Kalscheur et al., 1999). A reduction in dietary protein in mid and late lactation can reduce dietary cost of rations and reduce potential for excess N excretion. Likewise a reduction in crude protein during mid to late lactation may also maintain milk production (Kalscheur et al. 1999).

Urinary N excretion is important to measure due to increasing regulations concerning on farm nutrient losses and potential for environmental problems (Bannink et al., 1999). Within a dairy farming system, ammonia is a by-product of urea excreted in urine and feces. Microbial urease activity is intensified in dairy barns leading to increased amounts of urea N being converted to ammonia and carbon dioxide (Bannink et al., 1999). The authors developed prediction equations to help estimate the amount of N digested, amount excreted in milk, and amount excreted in urine. Digested N =(-42.5 x 20.3 + 0.738 x 0.039 x intake of N in g/day). Milk N = (46.62 x 6.48 + 3.681 x 0.252 x milk in g/day). Urinary N = (75.18 x 9.37 + 0.719 x 0.043 x (digested N – milk N)). N balance = (-101.3 x 20.6 + 0.158 x 0.039 x intake of N) (Bannink et al., 1999).

Nutrition to Reduce P Losses

Availability/Absorption

Availability of P for dairy cattle is 50% according to NRC (1989), which was reduced from 55 to 50% from the 1978 NRC to the 1989 NRC (Martz et al., 1990). The Nutrient Requirement Council (1989) has also established an availability of P to be 50% for all feedstuffs (Martz et al., 1990). The Agricultural Research Council has established absorption of 58% for feedstuffs (Martz et al., 1990). However, other studies have reported availability of P to be much higher.

In some trials, P availability to the animal has reached 96% (Satter and Wu, 1999). France has established P availability to be 70% (Ertl et al., 1998). From a nutritional perspective, it is better to increase availability of P instead of trying to decrease P content in concentrates and grains. Increasing availability of P could potentially lead to reductions in excessive amounts of P from mineral supplements (Ertl et al., 1998).

A variety of factors influence the availability of P. These include the source of P, intake levels of P, Ca:P ratio, intestinal pH, age of animals, and levels of Ca, Fe, Al, Mn, K, Mg, Vitamin D, and fat (Smith et al., 1966; Morse, 1992). Absorption is estimated to be close to 90% for calves and 55% for animals over 400 kg (NRC, 1989).

Phosphorus is absorbed through active and passive diffusion (Morse, 1992). Phosphorus absorption has been determined by dosing cows intravenously with ^{32}P. Absorption was found to be 64.4% for a ration containing alfalfa hay and 74.6% for an alfalfa-corn silage ration (Martz et al., 1990). Later, absorption rates from two rations were determined to be 84.5 and 93.9% (Martz et al., 1999). These percentages are much higher than the 50% absorption coefficient used by the NRC (1989).

Altering Suggested Dietary Levels of P

The NRC before 1965 suggested that an animal producing 45 kg of milk weighing 636 kg needed 80 g/d of P or 0.40% of DMI. Researchers participating on the NRC were skeptical and suggested this increase to 0.50% of DMI (NRC, 1965). Currently, the NRC (1989) recommends P levels between 0.34 and 0.41% of daily DMI depending upon milk yield and stage of lactation as it is rare to observe P deficiencies in modern dairy feeding systems (NRC, 1989; Spiekers et al., 1992). However, overfeeding of nutrients, especially P, is common practice across the United States (Van Horn et al., 1996; Chase, 1999). If total P inclusion in dairy rations could be reduced by 15% or more, then most rations would not need any supplemental P (Brintrup et al., 1992; Morse, 1996; Daniel et al., 1998; Sharpley et al., 1998).

A study performed by De Boer et al.(1981) was designed to determine if there were any adverse effects on animal health or milk production when alfalfa silage was supplemented with P, Cu, Zn, and Mn at 100, 150, and 200% of requirements (De Boer et al., 1981). The study indicated no reproductive problems or decrease in milk production associated with feeding differing levels (100, 150, and 200% of daily requirements) of these minerals and alfalfa silage. However, milk protein percentage increased linearly with increased mineral intake. This could be explained by the fact that as total mineral content increased, there was a tendency for cows to produce overall lower milk yields. Usefulness of this information lies in the fact that many dairy farms that feed only alfalfa silage have been accustomed to increasing amounts of minerals that are being fed to offset effects of increased Ca. This study indicates that there is no need to increase mineral content of rations above NRC (1989) recommendations. Likewise, in a subsequent study, diets in excess of requirements by 30 to 100% have no detrimental effects either physiologically or nutritionally on animals (Morse et al., 1992).

Lactating dairy cows were followed through three lactations to determine if P fed at either low or high levels (compared to NRC recommendations) caused any adverse effects (Brodison et al., 1989). The study showed no consistent significant effect of P content on reproductive performance, milk yield and composition, and body weight and condition score.

Phosphorus content should have no detrimental effects on reproductive efficiency if fed above a level of 0.24% of diet DMI. A possible reason for overfeeding P is to provide a margin of safety against reproductive problems (Satter and Wu, 1999). Reproductive efficiency can be affected if dietary levels of P drop below minimums needed to maintain microbial growth in the rumen, which is usually between 0.24 and 0.25% (Satter and Wu, 1999).

Other research has tried to determine if energy status and P content of diet affect postpartum health and lactation performance (Carstairs et al., 1981). Phosphorus was fed at 98 and 138% of NRC (1978) requirements. The study found that feeding excess nutrients to postpartum cows is neither beneficial nor detrimental, but resulted in an increase in feed expenses and wastage. As well, there was virtually no change in body weight between experimental groups. Interestingly, there was an increase in milk yield from animals fed the ration that contained 98% of NRC (1978) for P compared with rations containing 138% P on a DMI basis. The excess P could have interfered with feed digestibility, metabolism at the tissue level, or there could have been a reduction in milk for many unknown factors. Phosphorus did not affect milk composition during any of the trials. There was no difference in disease between high and low P rations.

Altering Dietary Ca:P Ratios

Smith et al. (1966) recommended an optimal ratio for absorption of Ca and P at 2:1 for most feeding situations. They reported that absorption and efficiency of Ca and P are reduced in cattle as the ratio between the two increases from 2:1 (Smith et al., 1966). However, ruminants are more resistant than monogastrics to wide swings in the Ca:P ratio. As more legumes are fed, wide ranges in Ca:P ratio should be expected as legumes are generally rich in Ca and low in P. Research performed using Holstein steers, and varying ratios of Ca and P (1:1, 2:1, 4:1, 8:1, 8:2, 8:4, and 8:8) determined that there were no detrimental effects on animal growth, rate of gain, skeletal development, health, blood P, and consumption of diet. The same experimental design was administered for lactating cows. Once again, the study found no detrimental effects on milk production, persistency of production or milk composition.

Research has also shown that wide Ca:P ratios in cattle can have a depressing effect on protein and energy digestibility, which is essential for milk production and animal health (Smith et al., 1966). Other studies have shown that Ca metabolism is influenced by levels of P in diets (Hibbs and Conrad, 1965). Bone mobilization of Ca may increase with increased P consumption (Hibbs and Conrad, 1965).

Another study focused on long term effects (over 2 yr) of Ca and P ratio differences on milk yield, reproduction, blood mineral values, and occurrences of disease within the herd (Steevens et al., 1971). Throughout the study, P was fed at two different levels, 0.4 or 0.6% of DMI. Blood P was found to be lower with the lower Ca:P ratio and increased proportional to the increase in dietary P. No significant differences were noted on milk yield for cows that were in the first 24 wk of the experiment. Milk composition varied between all breeds, but there was no significant difference in milk composition due to diet. During the first year on the study there was no difference in reproductive efficiency between or within herds. However, during the second year of the study, there were a larger number of services per conception within the group fed the 0.4% of DMI for P.

Inevitable/Fecal Loss of P

Phosphorus partitioning in lactating cows fed low (0.31%), medium (0.41%), or high (0.56%) P diets for 9 mo was evaluated (Morse et al., 1992). Phosphorus was excreted through milk, feces, and urine. In this study, total collections were obtained during wk 4, 7, 10, and 13. Phosphorus excretion during total collection for wk 4 was 88.2%, of which 68.6% was excreted through feces, 1% in urine, and 18.6% was excreted in milk. Urine accounts for only a very small amount of P excretion. Excretion of P in feces and milk varies with her P needs.

As P intake exceeds a cow's nutritional requirements, efficiency with which she utilizes P decreases, leading to increased P excretion in feces (Morse et al., 1992). When cows were fed a low P diet, for each g/d decrease in P intake, there was a decrease in P excretion of 0.55 g per day. Likewise, for each g/d increase in P intake, there was an increase in P excretion of 0.8 g per day (Morse et al., 1992).

It has been a normal practice to calculate inevitable loss of P on live weight of animals. However, more recent research has shown that inevitable loss of P is a function of DMI (Brintrup et al., 1992; Spiekers et al., 1992). Most endogenous P in ruminants is found in and recycled through saliva (Morse et al., 1992; Spiekers et al., 1992).

In one study, animals were fed P at either 60 or 68 g/d (Brintrup et al., 1992). Dry matter intake affected fecal losses of P more than did the live weight of animals. No significant effects were found on milk yield, protein content of milk, body weight, reproductive efficiency, health, or amount of P excreted in milk between the two groups. Higher P cows produced milk with higher fat concentrations (4.38% vs. 4.21%). There was a difference in the amount of P excreted through feces between two rations in which one was balanced for 73 g/d and the other was balanced for 86 g/d. Rate of P excretion was 43 and 55 g/d, respectively.

Summary and Study Objectives

Numerous authors spanning many different countries have addressed issues surrounding nutrient management since the mid 1900s. As well, federal and state governments have developed regulations to help minimize the effects of nutrient runoff and leaching. Nitrogen and P management will continue to dominate environmental research for many years to come, and farmers will be pressed to make management decisions based on environmental legislation.

Nutrient runoff, leaching, and volatilization have led to detrimental environmental effects that may jeopardize human health. Deteriorating bodies of water with loss of aquatic life and significant fish kills are an obvious outcome of eutrophication caused by nutrient runoff. Cyanobacteria growing in algae blooms can kill livestock and pose serious health threats to humans. Dinoflagellate *Pfiesteria piscicida* outbreaks have been shown to cause neurological damage in humans. Leaching of N into ground water has caused methemoglobinemia, which limits the oxygen carrying capacity of blood. This illness has been diagnosed in the deaths of infants. Acid rain has been and is a continuing problem caused by volatilization of N into the atmosphere. Not only are there environmental repercussions of overfeeding nutrients, it is very expensive to overfeed protein and add additional P to rations.

Much research has been dedicated to determine if additional N and P are necessary in dairy rations. Research has tried to alleviate nutrient loading to the land with developments including filtration systems, chemical amendments, cropping systems, genetic modifications, and nutrient budgeting. All offer valuable solutions to minimize the effects of overfeeding nutrients. However, nutrient balancing is the most influential in increasing farmer awareness on their farm and reducing nutrient loading to farm properties. Nutrient balances inform farmers of possible excessive nutrient inputs, utilization, and outputs.

The main objectives of this study were to use nutrient balances to help determine if there are excessive nutrients entering project farms. Also, the project was designed to determine if following NRC guidelines could reduce nutrient inputs. The project farms were chosen in the Shenandoah Valley of the Chesapeake Bay watershed, which has experienced algae blooms from eutrophication.

Materials and Methods

Field Study

Collaborator and Control Herds

Ten collaborator herds and ten control herds were part of a 2-yr field study with emphasis on reducing overfeeding of N and P to prevent ground water, surface water, and air pollution. Herds were chosen in the counties of Shenandoah, Rockingham, and Augusta, Virginia, with county extension agents selecting the farms. Historical farm data for 1998 was collected during the first farm visits in July of 1999 for the development of farm nutrient balances.

Collaborator herds had to be members of Dairy Herd Improvement Association (DHIA), achieve state average or above milk production, maintain state average or below days open, and use artificial insemination. Before the study began, each herd identified as a potential collaborator or control herd was visited and informed of the project and requirements for participation. During subsequent visits, herds were asked to sign a 2-yr contract, which indicated responsibilities of both the farm and research team.

Each collaborator herd was visited on a quarterly basis to collect fecal and blood samples. On a monthly basis, collaborator herds submitted forage and concentrate samples for nutrient analysis. In return, collaborators received $2 per milking cow listed on DHIA 202 sheets to offset veterinary expenses and nutritional consultation expenses. Collaborators also received MUN test results through DHIA and an interpretation of monthly MUN results. Lastly, collaborator herds received advice related to amount of N and P to feed their cattle.

The purpose of the control herds was to monitor management decisions affecting nutrient management without benefit of a dairy advisory teams (DAT). Control herds were chosen to investigate whether or not dairy producers would incorporate nutrient management changes on their own or if standard nutrient management practices would continue. Control herds received nutrient analyses of their forages and concentrates every third month and MUN analysis once per year. Control herds were not compensated for their participation, and received no interpretation of their results. Control herd information was not utilized for this section of the field study.

Research team members were responsible for the majority of the project data collection on all 20 participating herds. Blood samples were centrifuged for collection of serum, fecal samples were either frozen immediately or dried and ground, and feedstuffs were delivered to Virginia Tech's Forage Testing Lab for analysis. The majority of fecal samples were frozen for processing at later dates. Results of analysis of feedstuffs were sent to collaborators.

DHIA Records

DHIA records were monitored using PC Dart. Every month, collaborator herd data and every third month control herd data were downloaded from the Dairy Records Management System. Herd Summary Reports (form 202) and MUN data were saved for future reference. Milk urea nitrogen data were sent directly to collaborator farms with a letter interpreting results and suggesting management responses.

Farm Visits

During quarterly visits, 21 to 25 cows were randomly selected for fecal and blood sampling. Farm visits were coordinated with regular veterinary herd checks. A research team member was present during all data collections, sample collection, and to monitor the collection process. During periods in which herd veterinarians were not present, research assistants were responsible for blood and fecal sampling.

Dairy Advisory Teams

Collaborator herds also agreed to participate in DAT meetings. Dairy producers had full discretion in choosing members for the DAT, but most DAT consisted of the dairy producer, veterinarian, nutrition consultant, and the farm's extension agent(s). Teams were developed to offer insight and guidance to producers when making management decisions to improve farm viability. Each team was required to meet monthly for 3 mo and then once every quarter. Teams were urged to meet for roundtable discussions of issues facing the dairy producer. Issues for discussion included, but were not limited to, financial obligations, herd health, and formulation of dairy rations. Because the DAT were organized late in the first year of the study, none of the information collected could be presented here.

Forage and Feedstuff Collection and Analysis

Research team members visited collaborator herds once every 3 mo to collect forage and concentrate samples. During alternate months, DHIA technicians sent feed samples to Virginia Tech. Samples were analyzed for crude protein (AOAC, 1989), acid detergent fiber (Van Soest et al., 1991), and neutral detergent fiber (Van Soest et al., 1991). Dry matter content of samples was measured by drying (Precision Scientific 1504, Precision Scientific Company, Chicago, Il) at 60°C until a constant weight was achieved. Phosphorus analysis of feedstuffs was by AOAC (1965). Magnesium, calcium, and potassium were measured by flame spectrophotometry (Spectroflame Modula Tabletop ICP, Spectroflame, FTMOA85D, Spectro Analytical Instruments, Inc., Fitchburg, MA).

Fecal Collection and Analysis

Fecal grab samples were stored in coolers with ice packs (2 to 30 h) during transport. Samples were either frozen or immediately dried at 60°C for 15 d (Wisconsin Oven, UL 80, Memmert, West Germany), or until a constant weight. Fecal samples were ground through a 1-mm screen (Thomas-Wiley Laboratory Mill, Model 4, Thomas Scientific, San Fransico, CA). Dry ground fecal samples were stored at room temperature until analyzed for P content (AOAC, 1965).

Urinary Excretion Estimation

Urinary N excretion was estimated from MUN with prediction equations (Jonker et al., 1998). Phosphorus excretion through urine was assumed to be zero (Morse et al., 1992). Urinary N and P estimation were made due to difficulties experienced in urine sample collection. Most urine samples were contaminated by feces or vaginal discharge from sick cows and could not be used for measurement of urinary N or P excretion.

Blood Collection and Analysis

Blood samples were obtained from the tail vein using non-treated Vacutainers (Becton Dickinson Vacutainer System, 367214, Becton Dickinson and Company, Franklin Lakes, NJ). Blood was allowed to clot at room temperature and each sample was centrifuged for 10 min at 133 x g (Fisher Scientific, Fisher Centrific Model 228, Fisher Scientific, San Francisco, CA). Serum was collected and frozen for storage until later analysis. Serum was analyzed for urea N (Beckman Analyzer BUN Kit, 442750, Beckman Instruments), P (Beckman Analyzer PO_4 Kit, 465145, Beckman Instruments), and Mg (Beckman Analyzer Mg Kit, 445360, Beckman Instruments) in duplicate.

Estimated Whole Farm Nutrient Balance

Whole farm nutrient balance is an estimate of nutrient status of the farm. Nutrient balance includes nutrient accumulation, runoff from the surface or subsurface, leaching, and volatilization. Nutrient balance spreadsheets were developed for collaborator farms.

Farm information collected (fiscal year 1998) for these herds is shown below. Inputs and outputs were calculated on a total farm, per cow, and per ha basis. Inputs and outputs were reported on the nutrient budgeting spreadsheet as follows:

Inputs	Outputs
Quantity of purchased feed with nitrogen and phosphorus content	Quantity of milk
Type and quantity of fertilizer	Type and number of sold animals
Type and quantity of bedding	Type and quantity of sold forages and grains
Type and number of animals purchased	Type and quantity of manure removed
Type and quantity of legumes planted	
Quantity of rainfall	

Information was collected from the producer, feed salespersons, and fertilizer dealers. Whole farm nutrient balance was determined as nutrient inputs into the farm less nutrient outputs from the farm.

Purchased Feeds/Sold Forages and Grains

Producers and feed dealers were asked to provide information regarding amount and nutrient composition of purchased feeds for the whole farm for fiscal year 1998. Total kg of N and P from imported and exported feeds were calculated. Feeds consisted of concentrates for lactating cows, dry cows, and heifers and any other purchased feeds or commodities.

Bedding

Type and quantity of bedding were determined, and the N and P content of the bedding were estimated (Church, 1991).

Purchased Fertilizer

Records of fertilizer purchases were obtained from the producer or fertilizer supplier. Quantity purchased and N and P content were used to calculate quantity of N and P imported in fertilizers. Nutrient content of broiler litter (Church, 1991) was estimated for farms that used this as a fertilizer.

Atmospheric Deposition

Rainfall quantities and nutrient content of rain were obtained from state of Virginia climatology testing stations. Measurable elements included Ca (.05 mg/L), Mg (.011 mg/L), K (.016 mg/L), Na (.061), NH_4 (.22 mg/L), NO_3 (.84 mg/L), Cl (.12 mg/L), and SO_4 (1.30 mg/L) (Virginia Climatology Lab, Charlottesville, VA, 1998). Measurable amounts of P in rain were not recorded for Virginia in 1998. Each farm was assumed to have the rainfall per ha of the nearest climatology center. Composition of rain was assumed to be similar for all locations. Quantities of NH_4 and NO_3 deposited on the farm were estimated by multiplying the content of NH_4 and NO_3 by rainfall and farm ha.

Purchased Cattle/Sold Cattle

Number of animals sold, approximate body weight, and classification (i.e., cows, heifers, bulls, steers, or calves) were collected. For animals weighing more than 100 kg, P content of the animal was calculated as:

$$(10.6*W) - ((.00663*W^2) - 399),$$

where W represents the weight of the animal in kg (Georgievskii, 1982). The P content of animals less than 100 kg was assumed to be .7% (Van Horn et al., 1996). The N content of all animals was estimated as 2.2% of body weight (Van Horn et al., 1996). Total N and P exported in the form of animals was calculated from number of animals sold, body weight, and assumed N and P content.

N Fixation from Legumes

Types and acres of legumes planted were recorded for each farm. The N fixation from alfalfa was estimated as 212 kg/ha/growing season (Fribourg, 1995). No other legumes were planted on collaborator farms during this study.

Milk

Quantity of milk sold, milk protein concentration, and milk fat concentration was used to calculate the N and P exported in milk. The N content of milk protein was assumed to be 15.5% (Van Horn et al., 1997). The P content of milk was assumed to be .99 g/kg of 4% FCM (NRC, 1989).

Removed Manure

If farms exported manure during 1998, quantity of manure leaving the farm was recorded.

Nutrient Balance Spreadsheets

Nutrient balance spreadsheets were developed for collaborator herds following potential nutritional changes. Control herds were not analyzed, as they were not determined until later in the project. Quantities of N and P imported were calculated after rations were adjusted to meet herd requirements. Revised rations for collaborator herds were calculated based on NRC (1989) guidelines using average lactating cow body weight, milk yield, milk protein percentage, and milk fat percentage from December 1999 records. All cows were assumed to be multiparous and in mid lactation. Remaining inputs and outputs were not altered, as our purpose was to determine how changes in nutrition would influence total farm nutrient budgets from year to year.

Statistical Analysis

Statistical analyses of data were calculated by paired t-test and results were verified by ANOVA (Excel, 1998). Collaborator farms were analyzed and compared to one another for N and P in purchased feeds, purchased feeds/cow, purchased feeds/ha, purchased fertilizer, purchased fertilizer/cow, total N or P input, milk N and P, sold forages/cow, and change in nutrient retention. Bedding, atmospheric N from rain, purchased fertilizer, purchased cattle, N fixation, milk, sold cattle, sold forage, sold manure/cow and sold manure/ha were left constant for 1998 and post-change so that nutritional effects could be illustrated.

For statistical analysis, the null hypothesis was that there was no difference between 1998 data and NRC (1989) recommended data.

Results and Discussion

Field Study

During the first year (1999) of the project, two collaborator herds withdrew after 8 mo. One control herd became a collaborator herd, so the project continued with nine collaborator and nine control herds. Reasons for discontinuation from the field study were not a result of DAT meetings. One herd sold their cattle due to economic reasons. The other farm felt the effort involved in the project was too great for the value received. In all, seven herds were analyzed. Two collaborator herds, representing a commercial and purebred herd, were not analyzed due to lack of information. These farms did not keep accurate records to provide the information needed to develop a whole farm nutrient balance. Likewise, the control herd, which became a collaborator, was not analyzed as insufficient information was collected. Once again, this herd did not keep the records needed to calculate a whole farm nutrient balance.

Even though all herds were state DHIA average or above for milk yield (8864 kg) and days open (150) when selected, individual farm demographics varied greatly before and during the project. Tables 1, 2, and 3 illustrate changes within each herd for 1998, 1999, and 2000, respectively. There were no obvious trends either within or between herds. The following herd information is based on 2000 DHIA records.

Herd A averaged 286 cows, 33 kg milk/day, 3.69% fat, 3.00% protein, 10180 kg rolling herd average (RHA) milk production, 2.40 somatic cell score (SCS), 81 d to first service, and 123 d open. This herd was first out of the seven herds in RHA milk production. In addition, Herd A was first in days open out of the seven collaborator herds. Herd A data remained relatively constant throughout the first year of the project. Cow numbers remained stable along with percent fat, percent protein, RHA milk, days open, and days to first service. Milk production per day showed slight variation, which was likely due to seasonal weather changes. Herd A averaged 14.3 mg/dl for MUN throughout the same time frame, which was similar to the collaborator average of 14.4 mg/dl. From time of project initiation, Herd A lowered MUN values from 16.8 to 11.1 mg/dl. Thus, MUN analysis helped this herd to focus on reducing N loading in their rations. Forages from Herd A were similar to all collaborator farms. Corn silage averaged 39% dry matter (DM), 8.4% crude protein (CP), 21.7% acid detergent fiber (ADF), and 69.5% total digestible nutrients (TDN). Calcium, P, Mg, and K were average with values of .28%, .22%, .38%, and 1.23% respectively. The other major forage analyzed for Herd A was rye silage, which was similar to the rest of collaborator herds.

Herds A and C were owned by the same individual, but managed by different farm managers with different management styles. Herds A and C utilized a TMR dairy feeding program and the services of nutritionist for balancing their dairy rations. Both herds housed cattle in freestalls. Major differences in these herds were location of the dairies and cow numbers. Herd A milked approximately 100 more cows than Herd C.

Herd B averaged 158 cows, 31 kg milk/day, 3.70% fat, 3.22% protein, 9815 kg RHA milk, SCS of 3.00, 94 d to first service, and 136 d open. Herd B remained relatively constant throughout first year. Days open steadily increased throughout the year from 124 to 136, indicating possible problems in reproduction. However, fat, protein, and RHA milk remained constant. The MUN values (13.4 mg/dl) averaged slightly lower than the collaborator average of 14.4 mg/dl, suggesting that N content in this herd ration was appropriate. Corn silage fed on the farm was similar to all collaborator corn silage, except for CP content (10.7%); this herd used anhydrous ammonia as a silage preservative. Macromineral content of corn silage was similar to that of all collaborator corn silage. Rye silage was also fed to the herd. Crude protein of rye silage was 16.7%, and P was .29%. Herd B used a TMR dairy feeding program developed by a nutritionist. Cows were milked in a new herringbone parlor and were housed in freestalls.

Herd C averaged 147 cows, 38 kg milk/d, 3.70% fat, 3.20% protein, 10137 kg RHA milk, SCS of 3.00, 81 d to first service, and 133 d open. This herd had the highest milk kg per day and second highest RHA milk. As mentioned earlier, the same individual owned Herd A and C. Cow numbers ranged from 162 to 179 cows, milk/day varied 1.4 kg/d from test to test, and RHA milk fluctuated from 9875 kg to 10738 kg. The MUN analysis for the herd averaged 17.8 mg/dl, the highest of all collaborator herds. The herd appeared to be overfeeding N, which could have had detrimental effects on reproduction. The MUN ranged from 13.6 to 20.5 mg/dl. Interestingly, forage analyses on corn silage, rye silage, and barley silage were similar to averages of all collaborator herds feeding these forages. In addition, macromineral values for corn silage and rye silage were below collaborator averages.

Herd D averaged 96 cows, 33 kg milk/d, 3.48% fat, 3.20% protein, 9730 kg RHA milk, SCS of 3.50, 98 d to first service, and 147 d open. This herd had the highest SCS of all collaborator herds and the lowest fat percent. Milk/d and RHA milk remained stable, as did fat percent and protein percent. The MUN content averaged 14.2 mg/dl, similar to the average of all collaborator herds. Herd D used anhydrous ammonia to preserve their corn silage, which increased the CP percent of their corn silage relative to other collaborators (14.2%). Macrominerals were average for their corn silage (.28% P, .23% Mg, .36% Ca and 1.31% K). The rye silage fed to the cows was very wet (23% DM). The CP value averaged 17.75% with a TDN of 68.12%. Herd D also fed high moisture shelled corn (HMSC). Herd D HMSC averaged 9.2% CP and 85.73% TDN. These values were about the average of all four collaborators. Phosphorus, Mg, Ca, and K did not vary much from the collaborator average as Herd D values averaged .32, .14, .03, and .49%, respectively. Herd D was unique in that it fed soybean silage. The feed analysis was 53% DM, 18% CP, 34% ADF, 64% TDN, .34% P, .53% Mg, 1.28% Ca, and 2.95% K. Cows were housed in freestall barns and fed a TMR mixed by a stationary TMR mixer.

Herd E averaged 190 cows, 31 kg milk/d, 3.60% fat, 3.16% protein, 9997 kg RHA milk, SCS of 2.24, 101 d to first service, and 143 d open. This herd had the lowest SCS of the collaborators and tied with Herd F with the longest days to first service. There were no consistent trends in cow numbers, milk/d, fat percent, protein percent, RHA milk and reproductive measures throughout the first year of the project. Herd E MUN average was 13.1 mg/dl, the lowest of all collaborators. The management was focused on providing a dairy ration that did not overfeed N. This was a trait that had occurred before the beginning of the project. Forages included corn silage, rye silage, alfalfa silage, HMSC, and wheatlage, and were very uniform and similar to the other collaborators. This was the only farm that fed wheatlage and it averaged 55.67% DM, 12.22% CP, 29.25% ADF, 64.66% TDN, .4% P, .11% Mg, .32% Ca, and 1.63% K. Herd E was managed and operated by the owner. Cows were housed on a manure pack during the fall and winter seasons and allowed to graze in a rotational pattern during the spring and early summer. A TMR feeding program was in place and a nutritionist balanced the ration.

Herd F averaged 100 cows, 30 kg milk/d, 3.88% fat, 3.33% protein, 9020 kg RHA milk, SCS of 3.10, 101 d to first service, and 173 d open. Herd F had the lowest RHA milk and milk kg per day. Herd F also had the highest days open, SCS, and fat percent of all the collaborator herds. The farm was rented and cow numbers remained stable. According to MUN analysis, the herd was below (13.7 mg/dl) the collaborator average of 14.4 mg/dl. Forages for the farm consisted of corn silage and rye silage. Forage quality was acceptable as there were no obvious differences in the averages for Herd F compared with collaborator averages for both corn silage and rye silage. Herd F was limited in their ability to improve facilities as the farm was rented, but the parlor was updated and cows were housed in freestalls. A TMR was fed on the bunk and the farm utilized a nutritionist to balance rations.

Herd G averaged 115 cows, 35 kg milk/d, 3.83% fat, 3.28% protein, 9597 kg RHA milk, SCS of 2.80, 87 d to first service, and 155 d open. This herd remained very stable for milk kg per day, RHA milk, fat percent, protein percent, and days to first service. However, cow numbers, SCS, and days open were increasing slightly. Herd G dedicated a large amount of time to reproductive management because they milked and marketed purebred cows and sold purebred bulls. Herd average MUN was 14.2 mg/dl, which was similar to the average of all collaborators. Feedstuffs and forages included corn silage, rye silage, alfalfa silage, HMSC, and barley silage. The corn silage was of good quality and matched the averages of all collaborators. The rye silage and alfalfa silage were exceptional in comparison to their counterparts. Rye silage averaged 19.29% CP, 27.86% ADF, and 68.4% TDN compared with collaborator averages of 16.18% CP, 30.71% ADF, and 66.51% TDN. Alfalfa silage averaged 23.6% CP, 24.65% ADF, and 70.7% TDN compared with collaborator averages of 19.8% CP, 31.53% ADF, and 65.79% TDN. The HMSC and barley silage matched the averages of all collaborators tested. The farm owners performed all ration balancing on premises. Herd G used a TMR, freestall housing, and milked in a herringbone style parlor.

Herd Data Collection

The majority of herd collections were made during routine monthly veterinarian checks. Sample collection tended to be from cows that were either in early lactation (for pregnancy evaluation) or sick. To increase efficiency and to minimize stress on cows and managers, project coordinators felt that collections made during routine vet checks would be sufficient. Sampling herds on days other than vet checks would have yielded a more representative sample of cows that were not stressed due to calving problems or illness. Sick and/or metabolically impaired cows are more likely to have blood urea nitrogen (BUN) concentrations lower than herd average BUN for individual cows. Likewise, sick and/or metabolically impaired cows generally do not consume as much feed as healthy cows. Fecal samples could differ from healthy cows in P content, resulting in skewed data. On the other hand, early lactation cows generally consume more feed, causing elevations in BUN concentrations and possibly P content in feces.

Components of the Whole Farm Nutrient Balance

Whole farm nutrient balances were calculated to quantitatively estimate nutrient flows of N and P for the collaborator herds. The following sections describe the different variables of the whole farm nutrient balance spreadsheets and their relevance for each farm. Some farms had information to add in each section and some did not. Major points of discussion, such as individual farm scenarios, are addressed as well. Figures 1 and 2 illustrate the average percent of total N and P imports from different off farm sources. Figures 3 and 4 illustrate the average percent of total N and P exports form the farm.

Purchased Feeds/Sold Forages and Grains

Purchased feeds and sold forages and grains are shown in Tables 4 and 5. Total purchased N ranged from 11822 to 33922 kg/yr. Total purchased P ranged from 2257 to 6111 kg/yr. For the seven collaborator herds, purchased feeds consisted of high protein feed with minerals (bunk mix), concentrate pellets, which varied in crude protein content and mineral concentration, ground corn, cottonseed, and distillers dried grains. Each farm fed a different combination of these ingredients.

Grains were not sold from collaborator farms. However, corn silage and hay were sold from two of seven collaborator farms. On these two herds, total sold N for 1998 ranged from 1854 to 7556 kg/yr, and total sold P ranged from 288 to 1601 kg/yr.

Bedding

A table of bedding types and quantities of N and P from bedding is shown in Table 6. Bedding types included sawdust, peanut hulls, sand, and mats. Sawdust was the most commonly used bedding agent. Total imported N from bedding sources ranged from 23 to 2123 kg/yr. Total P from bedding sources ranged from 1 to 5120 kg/yr.

Sawdust contains much more P than peanut hulls. On the other hand, peanut hulls brought more N onto the farms than sawdust. This can be explained as peanuts are legumes and they fix N from the atmosphere. Those farms that used mostly peanut hulls imported more N onto the farm than P on a per cow basis. Farm G brought more N onto the farm in bedding than any of the other collaborator farms on a per cow and per ha basis, as they used both sawdust and peanut hulls. Phosphorus imports on a per cow or ha basis were not unusually high, though, as the majority of the bedding was peanut hulls. This information gives Farm G an opportunity to reduce N inflows onto their farm. Farm G could reduce the amount of bedding used or switch to all sawdust instead of a combination of sawdust and peanut hulls. Both suggestions could lead Farm G to reduce the amount of N being imported.

Farm E imported more P on both a per cow and per ha basis than any other farm. More than 44 kg of P was imported onto the farm on a per cow basis and 3.5 kg of P on a per ha basis. The sole source of bedding for Farm E was sawdust, and this farm used more sawdust on a per cow and per ha basis than did other farms. This high bedding use could be one area of management that Farm E could consider revising.

Bedding is important for cow comfort. However, dairy farmers need to realize that the source of bedding can contribute to excess N and P being imported to the farm. Sand or mats would be preferable, but handling and costs need to be analyzed. Sawdust and peanut hulls are inexpensive in the Shenandoah Valley, but the environmental impact from their use needs to be considered as well.

Purchased Fertilizer

Table 7 represents imported N and P used as fertilizer. All collaborator farms purchased N to spread as fertilizer in addition to manure N in 1998. Farms B and E were the only farms that spread supplemental fertilizer P in the form of broiler litter on their farms. Total purchased N fertilizer ranged from 159 to 30251 kg/yr. Total purchased P fertilizer ranged from 0 to 10844 kg/yr. Of all the farms, Farm B spread more N and P based on a per cow and per ha basis. In addition to manure spread on the farm, Farm B spread an additional 214.5 kg/cow of fertilizer N (15 kg/ha), and 77 kg/cow of fertilizer P (5.4 kg/ha). Herd D brought the least amount of purchased fertilizer N onto the farm. In addition to using farm waste as fertilizer, only 1.7 kg of N was imported per cow (.12 kg/ha).

Manure was not sold by any of the seven collaborator farms. While this helps to keep the collaborator farms self-sufficient and reduces crop fertilizer costs, this practice does not help reduce net farm nutrient balance. It has been common practice for dairy producers to acknowledge the N portion of manure and make adjustments when purchasing fertilizer N. However, it is necessary to consider every nutrient included in farm-produced manure and then purchase supplemental fertilizer accordingly.

Nutrients from Rain

Table 8 illustrates the nutrients deposited in rainfall for 1998 collected from different stations in the Shenandoah Valley. Nitrates, sulfates, and ammonia comprised over 90% of the total nutrients from atmospheric deposition in the project area. Other nutrients included Ca, Mg, K, Na, and Cl. It is clear that N and S are volatilizing into the atmosphere in different forms.

Table 9 shows total N from rain for the different collaborator farms in 1998. Nitrogen deposition from rainfall was proportioned to farm size and varied from 142 to 1201 kg/yr.

Purchased/Sold Animals

Only one of seven collaborators purchased cattle. On a per cow basis, the quantity of N and P brought onto the farm in purchasing cattle is minimal. However, few research studies have included purchased or sold cattle in the calculation of nutrient balances. On a per cow basis, Herd G brought 0.17 kg of N onto their farm in animals and 0.02 kg/ha. Even less P was brought onto the farm in purchased cattle as 0.04 kg was imported on a per cow basis (0.005 kg of P/ha).

Many animals were sold off collaborator farms (Table 10). All seven collaborator herds sold mature cows. Calves, heifers, and light and heavy steers made up the remainder of cattle sold. Five of the farms retained all calves born. Heifers were either used as replacements or fed out for beef purposes. Retained bull calves were fed out for beef purposes on five of the farms. One farm sold purebred Holstein bulls for breeding purposes. Herd B removed more N and P on a per cow basis than all other farms. A total of 10.4 kg of N and 3.2 kg of P were removed from the farm on a per cow basis. However, Farm F removed more N and P on a per ha basis than all other collaborator herds.

Clearly, selling of any type of animal is a means of diversification, and is a source of additional farm income, and removes N and P. Cattle are considered by many as a constant in nutrient flow on dairy farms, but there is a N and P fraction associated with each animal.

Nitrogen and Phosphorus Exported Through Milk

Table 11 illustrates milk production from the seven participating herds ranged from 1,079,546 to 2,818,118 kg/yr in 1998. Average milk production for the herds was 1,656,060 kg/yr. Exported N in milk ranged from 5355 to 14415 kg/yr. Average N exported through milk was 8336 kg. On a per cow basis, exported N in milk ranged from 49 to 71 kg/yr. Exported N in milk on a per ha basis ranged from 10 to 54 kg/yr. Likewise, Table 12 indicates that P exported in milk ranged from 1020 to 2706 kg/yr, with average P exported off the farm in milk being 1528 kg/yr. On a per cow basis, P exportation varied from 9 to 13 kg/yr. Variation in P exportation on a per ha basis was from 2 to 10 kg/yr. As far as trends concerning individual farms, no obvious trends were noticed as many variables could have caused an individual farm to be at the low end, high end, or middle of the ranges provided.

Farms C and E removed the most N in milk from the farm on a per cow basis, because milk production per cow was greater than all other farms. In other words, Farms C and E produced more milk from fewer cows. Farms E and G removed more P in milk on a per cow basis due to cow numbers and kg of P in milk.

Because N content was calculated from percent protein of milk, Farm C produced milk with the highest protein percentage of 3.8%, which is much greater than the national average for Holstein cattle. If the information recorded from farmer interviews was accurate, Farm C could have removed 71.3 kg/cow/yr of N through milk. If there was farmer error in reporting milk protein percent, Farm E would have removed more N on a per cow basis in milk than all other collaborator farms with 71.19 kg of N removed per cow/yr.

On a per ha basis, Farm F removed more N and P than all other collaborator farms with 21.67 kg of N and 4.132 kg of P being removed. This could be explained as Farm F farmed the smallest area of land compared with other collaborator herds.

Nitrogen Fixation

Of the seven collaborating herds, only two farms planted legumes in 1998 for a total of 9 ha. Specifically, Farm B planted 4.05 ha of alfalfa and Farm D planted 4.86 ha of alfalfa. The alfalfa fixed 1887 kg of atmospheric N in 1998. Nitrogen fixation of alfalfa was 212 kg/ha (Forages, 1995).

Utilizing more legumes in rations of dairy cattle in the project study would improve farm N utilization. As legumes grow, nodules on their root system fix N from the atmosphere. The fixed N can then be utilized by the legume for growth. Other forages grown need off farm sources of N for fertilizer. Therefore, the more legumes planted the less N needs to be purchased. Legumes added to dairy rations and crop rotations are a practical improvement for many dairy farms.

Nutrient Balances – Individual Farms Including Changes in Ration

Farm nutrient balances for collaborator farms are shown in Tables 13 through 19. Control herds were not analyzed, as they were not determined until later in the project. Nutrient balances were developed with both 1998 data and potential nutritional changes for N and P if NRC (1989) recommendations were followed. To isolate effects of nutrition on nutrient retention on the farm, the only variable that changed was the purchased feeds. Other variables were left constant to support this effect. Any reduction in farm N or P balance was considered to be a positive result, indicating that less N or P was remaining on the farm.

Farm A (Table 13) retained 30801 kg of N/yr within the farm in 1998. If appropriate nutritional changes were made and assuming all other aspects remained the same, N balance could have been reduced to 24613 kg/yr. Similarly, 1998 data on this farm indicated a surplus in P of 4925 kg/yr. If nutritional changes were made and other aspects of the farming situation (i. e., N fixation by legumes, rainfall, fertilizer and bedding purchases) remained the same, P surpluses could have been reduced to 1463 kg.

Herd B (Table 14) retained 31671 kg of N on the farm in 1998. After potential nutritional changes, the surplus of N increased to 44305 kg. While on most farms, revised feeding decreased surpluses, the opposite occurred on this farm because Herd B was underfeeding N during 1998. This was the only farm in which more N would be retained on the farm after appropriate nutritional changes were made. Phosphorus remaining on the farm decreased after making nutritional changes from 10338 kg in 1998 to 9992 kg.

Herd C (Table 15) had15276 kg/yr of N remaining on the farm. If NRC (1989) recommended nutritional changes were made, this could reduce N surplus to 10157 kg/yr. During 1998, 1735 kg/yr of P remained on the farm. If nutritional changes were made, this could be reduced to 411 kg.

There were 8083 kg of N remaining on the farm during 1998 for Herd D (Table 16). If nutritional changes were applied to the ration with everything else remaining the same, Herd D could reduce P surplus by 3472 kg. During 1998, there was a total of 1075 kg of P remaining on the farm. If nutritional changes were made, the farm could reduce P surplus by 145 kg.

Herd E is represented in Table 17, with a total of 11486 kg of N remaining on the farm in 1998. This could be reduced to 8378 kg if the dairy rations had been nutritionally altered to meet NRC (1989) recommendations. Likewise, whole farm P balance could have been reduced from 8535 kg in 1998 to 6365 kg if dietary P were corrected to NRC (1989) recommendations.

There was a net change in nutrient storage within farming system of Herd F (Table 18) of 14132 kg for 1998. If protein levels were decreased to meet NRC (1989) recommendations, 12244 kg of N would have remained on the farm. Phosphorus balance on this farm could be reduced by 245 kg from 1132 kg in 1998 to 886 kg if dietary P were reduced to NRC (1989) recommendations.

Lastly, Herd G is represented in Table 19. According to 1998 data, 12036 kg/yr of N would have remained on the farm. However, if dietary N were balanced using the recommendations of the NRC (1989), N balance would have been reduced to 6285 kg/yr. There were 2106 kg of P remaining on the farm in 1998. If recommendations from NRC (1989) were met, P could have actually been removed off of the farm by 148 kg.

Statistical Analysis Comparing Different Variables of the Whole Farm Nutrient Balance

Statistical analyses of data were calculated by paired t-test and results were verified by ANOVA (Excel, 1998). Paired t-test (Excel, 1998) was used to analyze the following data:

Nitrogen	Phosphorus
N in purchased feeds	P in purchased feeds
N in purchased feeds/cow	P in purchased feeds/cow
N in purchased feeds/acre	P in purchased feeds/acre
Total N input	Total P input
Change in nutrient storage for N	Change in nutrient storage for P

The null hypothesis was that variables tested would not cause a significant reduction in N and/or P balances for collaborator farms with weight of rejection determined at P<.05. Of ten variables tested, analysis indicated an acceptance of the null hypothesis for 5 variables. Variables in which the null hypothesis was supported were: purchased feeds – N (P<.33) (Appendix Table 1), purchased feeds/cow – N (P<.249495) (Appendix Table 2), purchased feeds per ha – N (P<.07) (Appendix Table 3), total N input (P<.33) (Appendix Table 4), and change in nutrient storage – N (P<.33) (Appendix Table 5). In other words, the previous variables had no effect on N retention on the farm.

Interestingly, none of the variables associated with N resulted in significant reductions of on farm N. Even though there is more N kg being imported onto the farm than exported, there is not enough of a difference to establish a significant difference on a purchased feed, purchased feed/cow, purchased feed/ha, total N input, or total change in nutrient storage basis.

Observations from initial collaborator visits established ideas that N utilization had become an issue of importance for these farms and nutritional consultants before this study began.

With results of the statistical analyses from these collaborator herds, it appears that educational programs delivered by local cooperative extension agencies and other state and federal agencies have worked to increase awareness of N underutilization, which could cause runoff to the Chesapeake Bay watershed, leaching into local groundwater sources, and increased volatilization. However, the collaborator farms used for this study represent a small part of the total dairy farming industry for Virginia and the country as a whole. Emphasis should still remain in lowering N runoff, leaching, and volatilization. With advances in dairy nutrition focusing more on total absorbable aspects of the diet (NRC, 2000), less emphasis can be placed on crude protein values, which tend to increase total N levels of the ration.

Variables that influence change on nutrient balances for collaborator farms were purchased feeds – P ($P<.01$) (Appendix Table 6), purchased feeds per cow – P ($P<.01$) (Appendix Table 7), purchased feeds per ha – P ($P<.01$) (Appendix Table 8), total P input ($P<.01$) (Appendix Table 9), and change in nutrient storage – P ($P<.01$) (Appendix Table 10).

Statistical analysis of purchased feeds – P shows significant reductions in P balance are possible if less P is purchased through feeds. If farm nutritional consultants could more closely meet the P requirements of the cows with farm produced feeds instead of purchased feeds, less P would be imported from feeds.

If more farm produced feeds were fed, less P would be purchased in feeds to supplement additional needs the cows may have for P. This has an additional benefit in that farm produced feeds could utilize soil P for growth. This would reduce the amount of accumulated P in the soil that could runoff.

If all P inputs (feeds, bedding, fertilizer, and cattle) were reduced on our study farms, the significance would be greater. This is why farm management plays an important role in nutrient management. If a dairy farm could reduce or switch to a bedding source that was lower in P, less P would be imported onto the farm. Farmers need to have soil analyses performed to determine if additional P for crops is necessary. If economical, dairy farmers could purchase female replacements from off farm sources. Instead of bringing additional purchased feeds onto the farm to feed young stock, which imports the majority of nutrients, import the animal, which brings fewer nutrients onto the farm. Likewise, purchasing feeds based on nutrient requirements of lactating dairy cows would reduce total P importation and could reduce feed costs.

When all of the previous P variables are evaluated, they exhibited a significant effect on P balance on the farm. This study focused mainly on reducing P through nutrition. However, all previous variables could affect total P balance either positively (reducing net P balance on the farm) or negatively (increasing net P balance on the farm). When it comes to P management, dairy farmers have an ultimate responsibility to try to reduce imported P whenever possible. Actions such as these not only help the environment and surrounding areas, but also help to close political gaps that have been formed between the farming and non-farming communities.

Appendix Table 11 represents the mean and standard deviations for 1998 and post nutritional change data for each variable. This table is an illustration of how each variable compared between 1998 and post nutritional change data. Appendix Table 12 presents mean differences between variables for 1998 and post nutritional change data and standard error of mean differences.

Nutrient Balance – Complete Field Study

Effects of Reducing Purchased Feeds on Nutrient Balances

According to Klausner et al. (1998), nutrient inputs typically exceed outputs for N and P by 300 to 800%. On average, N inputs exceeded N outputs by 290% on our Shenandoah Valley project farms (Table 20). On individual farms, this ranged from 200 to 470% for N. Phosphorus inputs exceeded exports by 320% on average, with a range of 170 to 600%. These values were similar to those reported by Klausner et al. (1998). Some farms might have purchased more feeds; still others might have been more efficient in their milk production. Most farms expressed some type of excess in nutrient inputs as opposed to nutrient outputs.

Utilizing data collected in 1985 from a Pennsylvania dairy farm, Bacon et al. (1990) demonstrated that nutrient inputs exceeded outputs by 210 and 260% for N and P, respectively. The same dairy experienced a 200% excess in inputs versus outputs for both N and P in 1986. The main difference in nutrient excess between years was the result of feeding less purchased feeds in 1986. Between 1985 and 1986, this dairy could potentially experience a nutrient reduction of 110% for N and 140% for P. Bacon et al. (1990) also demonstrated that 54 and 62% of N and P, respectively, were either lost or accumulated within the soil. After a reduction in purchased feeds in 1986, 51% of the N and 50% of the P that entered the farm was either lost or accumulated.

When analyzing our data for N and P in purchased feed on a per cow and ha basis, results from the Shenandoah Valley project indicate the possibility of reducing amounts of N and P more than the Bacon et al. (1990) study. Nitrogen and P difference in purchased feed was approximately 15 kg and 7 kg greater in our project. However, P reductions in purchased feed on a per ha basis were greater in the Bacon et al. (1990) study. The Bacon et al. (1990) study yielded reductions that were approximately 120 kg and 10 kg greater in N and P on a per ha basis than our study.

Aarts et al. (1988) reported excesses of N and P of 690% and 300%, respectively, for specialized dairy farms in the Netherlands. In later studies involving a Netherlands dairy, Aarts et al. (1992) compared differing nutrient management systems. In a “current” farm system (representative of a typical Netherlands dairy farm), N inputs typically exceeded outputs by 670%. Phosphorus inputs exceeded outputs by 2.8-fold. During the system II design of the Aarts et al. (1992) study, cow numbers per ha were reduced, purchased fertilizers were reduced, and purchased concentrates were reduced. When N inputs were compared with N outputs, inputs exceeded outputs by 340%, which identified a reduction in N coming onto the farm compared with the "current" farm system. Remarkably, all of the P that entered the farm was removed through milk and meat for the system II design (Aarts et al., 1992).

Aarts et al. (1992) performed yet a further improved dairy management system labeled as system III. This system reduced further the cow numbers per ha, reduced purchased fertilizers, and reduced concentrates from the system II design. The system III design showed another reduction in N balance. In the revised system III, N inputs exceeded exports by 260%, which was an improvement over both the "current" and system II designs. As in the system II design, all P that was imported on the farm was removed from the farm.

When purchased feeds per ha were analyzed for N and P for all three systems, reductions in both N and P were obtained. Results from this study suggest that N in purchased feeds per ha could be reduced by 78 kg per ha, and P in purchased feed per ha could be reduced by 15 kg. However, the feasibility of this study needs to be questioned. There might not be enough landmass to reduce the cows/ha needed to initiate similar programs. Likewise, this study is based on grazing herds that consume large amounts of N from pasture. Therefore, grazing herds in this study probably have an inverse situation from the Shenandoah Valley project. Importing grains could be expensive in the Netherlands, which would limit the amount of feed fed per animal. If less feed is fed per animal less total P is fed.

Data from the Shenandoah Valley project indicate significant reductions in P in purchased feed per ha are possible if rations are balanced according to NRC (1989) guidelines. Results from our study indicate much less of a decline in N and P in purchased feeds per ha, 10 kg per ha reduction and a 4 kg per ha reduction respectively, than the Aarts et al. (1992) study. Unlike the Aarts et al. (1992) research trial, our study did not reduce cow numbers per ha which could have increased the difference between our 1998 and post nutritional change data yielding greater reductions in N and P in purchased feed per ha.

Research conducted by Wang et al. (1999) also supported Klausner's (1998) findings. Wang et al. (1999) developed a 15 yr study in which baseline data on Cornell's Research Dairy Farm yielded nutrient imports exceeding exports by 300% and 350% for N and P on the farm. However, after 15 yr, a nutrient imbalance of 340% and 330% for N and P was obtained. Interestingly, over the 15 yr, N balance increased and P balance remained relatively constant. According to the author, as milk production increased during the study's 15 yr trial, more purchased feeds were needed to support higher milk production. Even though the herd milk production increased by 44%, the N and P content of the exported milk did not offset the increase in N and P coming onto the farm from purchased feeds. This in turn led to the increase in N and P balance over 15 yr.

Not only did the N and P balance for this study increase compared to the Shenandoah Valley project, the N and P in purchased feeds on a per cow and ha basis increased between 1979 and 1994 as well. Nitrogen in purchased feeds increased by 74 kg and P increased by 17.5 kg on a kg/cow basis. Likewise, N and P on per ha basis in purchased feeds followed the same trend with N increasing by 54 kg and P increasing by 13 kg. This would be expected since the author was trying to demonstrate how purchased feeds would need to increase to meet higher milk outputs and the results that increasing purchased feeds would have on a nutrient balance.

During the Shenandoah Valley project, the milk production was left constant to illustrate how simple nutritional changes to support current milk production could reduce N and P balance. Our data suggest that N and P for purchased feed, purchased feed per cow, purchased feed per ha and total farm nutrient balance would decrease if nutritional changes were made to more accurately balance dairy rations for current milk production. Results from the Shenandoah Valley project suggest that N in purchased feeds, purchased feeds per cow, purchased feeds per ha and total nutrient balance would decrease on average of 2996 kg, 31 kg, 10.7, and 2997 kg respectively. Likewise, P in purchased feeds, purchased feeds per cow, purchased feeds per ha, and total nutrient balance would decrease on average of 1386 kg, 12.5 kg, 4 kg, and 1575 kg respectively. A comparison of the previous works with the Shenandoah Valley project can be found in Figure 5. The Shenandoah Valley project compared favorably with the Bacon et al. (1990) study and both Wang et al (1979) and Wang et al. (1994) studies. The Klausner et al. (1998) and both Aarts et al. (1988) and Aarts et al. (1992) studies indicated much higher N and P inputs over exports than the Shenandoah Valley project.

In study by Korevaar (1992), 85% of the N and 67% of P that entered the farm was lost or accumulated on the farm (Korevaar, 1992). Korevaar (1992) suggested that reductions in N inputs and surpluses were possible if farms would spread manure during growing seasons for maximal crop uptake, increase feeding of on farm forages to reduce imported feeds, reduce cattle per ha, and accurately feed animals for proper nutrition.

Van Keulen et al. (1995) developed a nutrient budget for an experimental Netherlands dairy farm on a kg/ha basis. Findings show that 71% of the N imported onto the farm remained within the farm system. Furthermore, 52% of the P remained on the farm. Farms that participated in the Shenandoah Valley project had 63.3 and 61.7% nutrient inputs as a percentage of net nutrient excess for N and P, respectively (Table 21).

Likewise during the Van Keulen et al. (1995) study, results from the nutrient budget for the experimental dairy farm were compared to that of Aarts et al. (1988). Research findings show that extensively managed farms could reduce the amount of N and P input onto the farm on a per ha basis. However, when study farms on the Aarts et al. (1988) trial were allowed to manage operations as usual, nutrients in purchased feeds increased over the experimental farm of Van Keulen et al. (1995). Study farms on the Shenandoah Valley project yielded results that were better than both of the previous two trials. On our study, purchased N and P per ha were 10.7 kg and 4 kg respectively, if nutritional changes were made. The Van Keulen et al. (1995) study reported N and P in purchased feeds on a kg per ha basis as being 123 and 21.4

respectively. Likewise, the Aarts et al. (1988) study reported N on a kg per ha basis for extensively and intensively and P on a kg per ha basis for extensively and intensively managed farms as being 80, 199, 15, and 36 respectively. All of this information reiterates the fact that farms in the Shenandoah Valley are managing nutrients in purchased feeds more closely than other areas of the world.

Frink (1969) calculated nutrient budgets for dairy farms in Connecticut. Results of this study parallel the findings of our study and other studies reporting that more nutrients are imported than exported. In comparing the Frink (1969) study with that of the Shenandoah Valley project, it appears that dairy farms have made substantial reductions in both N and P in purchased feeds per cow as well. The research of Frink (1969) found that 81 and 18 kg of N and P respectively were imported onto the farms on a per cow basis as compared to the Shenandoah Valley project, in which 31 and 12.5 kg of N and P on a per cow basis were imported. It appears that during the 32 years between these two studies environmental awareness had been raised and dairy farms and nutritional consultants reacted.

In a study performed by Anderson and Magdoff (2000), nutrient balances on 45 Vermont dairy herds and 1 New York dairy indicated that 57% of the P being brought onto these farms was not exported either through milk, animals, or sold manure. Furthermore, of all imported sources of P, feeds and minerals comprised 65% of the total P being brought onto the study farms, and 35% of the total P was brought onto the farm in fertilizer.

In all comparative research trials, there is substantial evidence that indicates large amounts of N and P are remaining within the dairy farming system. With changes in feeding practices, reductions of N and P on the farm are possible.

Effects of Reducing Other Variables on Nutrient Balances

If our research farms had adjusted their rations to meet NRC (1989) requirements and if no excess fertilizers were used on these farms compared with 1998 data, the percentage difference between nutrient inflows could potentially be reduced to 17.2 and 36.4% for N and P, respectively (Table 22). Percentage difference for N could have been greater (34.5%) if farm B 1998 data is removed from the equations. Farm B data indicated that protein was underfed for 1998. The study indicated that properly balanced dairy rations could significantly reduce P balance on project farms and that nutrient budgets are effective tools to help increase dairy awareness and efficiency.

Nutrients removed through milk and culled or sold animals in project farms averaged 32.6 and 34.6% for N and P, respectively (Table 23). This is higher than previous work of 14% for N (P was not calculated) (Korevaar, 1992). Aarts (1988) reported a nutrient recovery for N and P of 14.5 and 32.9%, respectively for milk and sold stock. Korevaar (1992), using the work of Aarts et al. (1988) reported a 14% N recovery in milk and meat for dairies in the Netherlands.

In comparing these resources, it appears that farms on our study were more efficient than dairy farms previously studied. However, as dairy farming becomes more intensive, an increase in production is expected and higher culling rates are likely to follow leading to more nutrient removal from the farm in the form of milk and culled animals. This might explain the increased nutrient recovery seen in our study as compared to Aarts et al. (1992) and Korevaar (1992). Percentage of nutrients removed through milk and culled or sold animals ranged from 19.6 to 43.8% for N and 14.1 to 53.8% for P on study farms.

When sold crops are considered along with removed milk and animals, the average nutrient removal from the farm for N increased to 36.7% and P increased to 38.4% (Table 24). Nitrogen ranged from 21.3 to 50.5% and P ranged from 16.6 to 60% on Shenandoah Valley project farms. While sales of crops are responsible for removing some nutrients, it is evident that increased milk production, sale of livestock, and culling are responsible for the majority of the nutrients leaving dairy farms on this study. If more efficient feeding strategies are utilized resulting in more efficient milk production, there is some potential to remove nutrients off the farm, leading to a more environmentally stable production agriculture situation. Korevaar (1992) has estimated that by using an optimized dairy management strategy, nutrient surpluses of N and P could potentially be reduced by as much as 70%, which appears to be a very lofty goal.

Conclusions

Future Project Recommendations

Nutrient management is a serious issue for the Shenandoah Valley, as evidenced by the response and willing participation of dairy producers in the target area. If a similar project were to be designed in the future, several project design issues need to be addressed and are indicated here. First, it was the intent of the research team to acquire a representative sample of the cows in each dairy herd during collection periods. However, because of the manner in which cows were selected, herd checks continually represented cattle that were in early lactation. While there were cattle tested in mid to late lactation, the majority of the samples were taken from early lactation cows.

Next, if this project is to be duplicated in the future, great strides need to be taken to maintain a research team that will remain stable through the entire duration of the project. Throughout the first year of a research trial of this magnitude, trust and respect need to be established between the research team and collaborator farms. There was a change in attitude on behalf of the collaborator farms once another research team member was introduced. Making changes of this magnitude during the middle of a research project establishes credibility conflicts directed toward research institutions and research team members.

Nutrient Reductions

Reductions in the amount of N remaining within a dairy farming system are possible, but not significantly possible, if nutritional changes are made following NRC (1989) guidelines. For example, excluding Farm B, farms in this study could potentially reduce N remaining on the farm by an average of 5602 kg. Farms varied in possible N reductions from 1888 to 11554 kg. Farm B was excluded from this calculation as this farm needed to feed more N to the cows according to NRC (1989) recommendations, which would result in a net importation of N.

A reduction in P remaining on dairy farms is statistically achievable through nutritional changes on collaborator farms using NRC (1989) recommendations. The average reduction in P balance for study farms amounted to 1096 kg. This average encompassed a range of 245 to 3463 kg of P reduction through nutritional changes.

Even though nutritional changes have shown reductions in nutrient losses for study farms, only two farms could show a total net exportation of nutrients. In other words, Farms D and G could potentially export more nutrients (N and P for Farm D, P only for Farm G) from the farm than what was imported. Reductions in N and P are results of altering collaborator dairy rations according to NRC (1989). Reductions outlined previously do not include possible increases in milk production, reductions in bedding, or cow number changes.

NRC (2001) Improvements

The new NRC (2001) dedicates an entire chapter to dairy cattle nutrition and its possible effects on the environment. Even though the NRC subcommittee grants that nutrient loss through feces and urine is inevitable, they reiterate the fact that dairy cattle should be fed to meet but not exceed their nutrient requirements (NRC, 2001). The NRC (2001) also recognizes that P content in dairy feeds across the nation averages 0.52% of the ration DM for high producing dairy cows. In an attempt to manage the influx of P on dairy farms, the subcommittee has adopted absorption coefficients for forages (64%), concentrates (70%), and inorganic sources of P (> 70%) (NRC, 2001). This was done to help farmers and nutritional consultants balance P requirements for dairy cattle more accurately (NRC, 2001). Likewise, elements of dairy cattle nutrition have been expanded to help reduce possible N overfeeding. For instance, amino acid equations are being more closely calculated to optimize milk production and protein. The subcommittee feels that formulation of diets that, "manipulate the quantity and composition of peptides supplied to the ruminal microorganisms might improve the efficiency of microbial protein synthesis (NRC, 2001)."

Broad Project Overview and Final Comments

The information provided herein has serious implications for the dairy industry of the Shenandoah Valley of Virginia. This area has been targeted as an area with elevated soil P levels. A reduction in whole farm P balance could help to reduce elevated soil P and other linked problems associated with large quantities of P remaining on the farm. Likewise, the same is true for N. If a reduction in N can be made through nutritional changes, there is the potential to reduce N pollution of ground water, surface water, and the atmosphere. A larger issue to consider is the fact that the Shenandoah Valley is a contributor of the Chesapeake Bay Watershed. If dairy producers are polluting their own land, runoff is also polluting the watershed. Therefore, a reduction in N and P of any quantity is advantageous to the entire area.

Figures 1, 2, 3, and 4 illustrate the importance of reducing nutrients entering the farm and how nutrient removal can reduce the overall nutrient surplus on the farm. From Figures 1 and 2, it is obvious that imported feeds bring the majority of the total nutrients onto the farm (65% of N and 52% of P). However, reducing imported fertilizer is important as it accounts for 27% of N and 28% of P for total inputs. Altering bedding sources could reduce the amount of P entering the farm as well (Figure 2). Exporting milk removed the greatest percent of nutrients from the farm (54% of N and 52% of P) as shown in Figures 3 and 4. However, sold forages also reduced nutrients remaining on the farm. Utilizing more farm-raised forages to increase milk production can also reduce nutrient surpluses. Either reducing imported nutrients, producing more milk with more on farm forages, or both can lead to beneficial environmental impacts.

As a whole, all of the farms that participated in this study realize the need for nutrient management on their farms. However, with the day-to-day activities of managing a dairy farm and moderately low milk prices, most dairy farmers would admit that nutrient management is not a priority.

Table 1: Herd comparisons from Herd 202 Sheets, May 1998.

Herd	Cows	Milk kg/d	RHA Milk kg	SCS[a]	% Fat	% Protein	Days Open	Days to First Service
A	241	39	10208	2.60	3.70	3.10	129	100
B	160	32	9723	3.10	3.55	3.20	124	100
C	146	39	10477	3.30	3.65	3.20	130	83
D	87	37	9776	3.60	3.50	3.20	152	101
E	162	38	10170	2.20	3.60	3.18	137	108
F	108	37	8910	3.10	3.80	3.30	151	113
G	85	35	9603	2.20	3.78	3.20	141	97

[a] Somatic Cell Score

Table 2: Herd comparisons from Herd 202 Sheets, May 1999.

Herd	Cows	Milk kg/d	RHA Milk kg	SCS[a]	% Fat	% Protein	Days Open	Days to First Service
A	237	37	10028	2.80	3.75	3.15	123	86
B	155	33	9754	3.00	3.53	3.23	127	94
C	147	41	10338	3.00	3.66	3.21	135	81
D	100	35	9588	3.70	3.55	3.19	148	90
E	137	36	9899	1.80	3.59	3.20	129	86
F	130	35	8982	3.30	3.78	3.25	162	105
G	100	34	9416	2.50	3.81	3.23	149	98

[a] Somatic Cell Score

Table 3: Herd comparisons from Herd 202 Sheets, May 2000.

Herd	Cows	Milk kg/d	RHA Milk kg	SCS[a]	% Fat	% Protein	Days Open	Days to First Service
A	286	33	10180	2.40	3.69	3.00	123	81
B	158	31	9815	3.00	3.70	3.22	136	94
C	147	38	10137	3.00	3.70	3.20	133	81
D	96	33	9730	3.50	3.48	3.20	147	98
E	190	31	9997	2.24	3.60	3.16	143	101
F	100	30	9020	3.10	3.88	3.33	173	101
G	115	35	9597	2.80	3.83	3.28	155	87

[a] Somatic Cell Score

Table 4: Purchased feeds for each farm in 1998.

Farm	Farm Feedstuffs	Purchased Feed (kg)	Avg. CP %	Feed N (kg)	Total N (kg)	N/cow (kg)	N/ha (kg)	Avg. P %	Feed P (kg)	Total P (kg)	P/cow (kg)	P/ha (kg)
A	Bunk Mix	323673	29.27	15156	33922	135	38	0.42	1351	6109	24	7
	Pellets	510400	22.98	18766				0.93	4759			
B	20% Dairy	176818	23.00	6507	16499	117	8	0.71	1255	3064	22	2
	Bunk Mix	90818	34.00	4941				0.86	781			
	20% Pellets	137273	23.00	5052				0.75	1030			
C	Bunk Mix	207655	30.01	9971	22600	155	16	0.41	841	3664	25	3
	Pellets	343873	22.96	12631				0.82	2820			
D	Bunk Mix	447273	17.20	12309	12309	138	9	0.52	2326	2327	26	2
E	Bunk Mix	324936	18.92	9838	15109	130	11	0.84	2729	3636	31	3
	Pellets	121002	25.73	4981				0.70	850			
	Ground Corn	19868	9.00	286				0.28	56			
F	Bunk Mix	635697	19.00	19325	19327	177	78	0.36	2289	2290	21	9
G	Bunk Mix	79073	42.80	5415	11818	131	17	0.56	443	2255	25	3
	Cottonseed	99091	18.83	2985				1.30	1288			
	Distillers	47273	26.99	2041				0.56	265			
	Pellets	21091	40.89	1380				1.24	261			

Table 5: Kilograms of N and P sold from forage in 1998.

Farm[a]	Type of Fertilizer	Total sold (kg)	N from each source (kg)	Total N (kg)	N/cow (kg)	N/ha (kg)	P from each source (kg)	Total P (kg)	P/cow (kg)	P/ha (kg)
B	Corn Silage[b] Hay[b]	509091 50000	6516 1040	7556	54	4	1476 125	1601	11	1
C	Corn Silage[b]	263636	4079	4079	28	3	633	633	4	.5

[a] Farms A, D, E, F, and G did not sell forages during 1998.

[b] Nitrogen and phosphorus content provided by Virginia Tech Forage Testing Lab, Blacksburg, VA.

Table 6: Kilograms of N and P from purchased bedding in 1998.

Farm	Bedding	Total (kg)	N from bedding[a] (kg)	Total N (kg)	N/cow (kg)	N/ha (kg)	P from bedding[a] (kg)	Total P (kg)	P/cow (kg)	P/ha (kg)
A	Sawdust	118182	201	201	1	.2	1761	1761	7	2
B	Mats	0	0	0	0	0	0	0	0	0
C	Sawdust	45455	77	77	.5	.06	677	677	5	.5
D	Peanut Hulls	1818	23	23	.3	.02	1	1	.01	0
E	Sawdust	343636	584	584	5	.4	5120	5120	44	4
F	Sand	0	0	0	0	0	0	0	0	0
G	Peanut Hulls Sawdust	166364 27273	2076 46	2123	24	3	116 406	523	6	1

[a] Book values used for bedding nutrient content (Church, 1991).

Table 7: Kilograms of N and P from fertilizer sources in 1998.

Farm	Type of Fertilizer	Total (kg)	N from each source (kg)	Total N (kg)	N/cow (kg)	N/ha (kg)	P from each source (kg)	Total P (kg)	P/cow (kg)	P/ha (kg)
A	Nitrogen[a]	35875	11480	11480	46	13	0	0	0	0
B	Broiler Litter[b]	599091	28469	30251	215	15	10844	10844	77	5
	Nitrogen[a]	5568	1782				0			
C	Nitrogen[a]	23011	7364	7364	50	5	0	0	0	0
D	Nitrogen[a]	498	159	159	2	.12	0	0	0	0
E	Broiler Litter[b]	81818	3888	3888	34	3	1481	1481	13	1
F	Nitrogen[a]	1705	545	545	5	2	0	0	0	0
G	Nitrogen[a]	1477	650	650	7	1	0	0	0	0

[a] Nitrogen content provided by Houff's Feed and Seed, Weyers Cave, VA.
[b] Nitrogen and phosphorus content provided by Van Horn (1997).

Table 8: Atmospheric nutrients.

Nutrients	mg/L
Ca	0.05
Mg	0.01
K	0.01
Na	0.06
Cl	0.12
SO4	1.30
NH4	0.22
NO3	0.84
P	0.00

[a] Rain composition was obtained from the Virginia State Climatology Office, Charlottesville, VA.

Table 9: Kilograms of N from rain in 1998[a].

Farm	Total N (kg)	N/cow (kg)	N/ha (kg)
A	541.364	2	.6
B	1201.441	9	.6
C	824.693	6	.6
D	867.642	10	.7
E	815.793	7	.6
F	142.389	1	.6
G	422.729	8	1

[a] Rainfall amounts and composition obtained from the Virginia State Climatology Office, Charlottesville, VA.

Table 10: Total kg of N and P left farm from sold animals[abc].

Farm	Animal Type	Average Animal Wt. (kg)	Number of Animals	Total N (kg)	Total Farm N (kg)	N/cow (kg)	N/ha (kg)	Total P (g)	Total Farm P (kg)	P/cow (kg)	P/ha (kg)
A	Cows	682	56	840	928	4	1	209800	238	1	.3
	Calves	39	102	88				27846			
B	Cows	602	46	609	1463	10	1	164655	444	3	.2
	Light Steers	250	80	440				146930			
	Heavy Steers	352	46	356				115493			
	Heifers	522	5	57				16638			
C	Cows	682	47	705	1030	7	1	176082	265	2	.2
	Heifers	591	25	325				88747			
D	Cows	500	38	418	600	7	.5	123253	183	2	.1
	Light Steers	319	26	182				60001			
E	Cows	591	21	273	652	6	.5	74547	154	2	.1
	Heavy Steers	864	18	342				68582			
	Heifers	568	2	25				6966			
	Calves	39	14	12				3822			
F	Cows	591	30	390	529	5	2	106496	138	1	.6
	Heavy Steers	909	5	100				18791			
	Calves	39	45	39				12285			
G	Cows	636	19	266	524	6	1	69555	152	2	.2
	Light Steers	227	16	80				26649			
	Bulls	409	11	99				31101			
	Heifers	455	7	70				21360			
	Calves	39	11	9				3003			

[a] For animals weighing more than 100 kg., P was calculated by: $10.6*W-.00663*W^2-399$ (Georgievskii, 1982).

[b] The whole body N content was established at 2.2% (Van Horn, 1996).

[c] The whole body P content for animals weighing less than 100 kg. was established at .70% (Van Horn, 1996).

Table 11 Kilograms of N exported from the farm in milk in 1998.

Farm	Milk (kg)	Milk Protein Percent	Protein (kg)	N[a] (kg)	N/cow (kg)	N/ha (kg)
A	2818118	3.30%	92998	14415	57	39
B	1662590	3.15%	52372	8118	58	10
C	1778935	3.80%	67600	10478	71	19
D	1150000	3.20%	36800	5704	64	11
E	1696793	3.14%	53279	8258	71	15
F	1079545	3.20%	34545	5355	49	54
G	1196439	3.25%	38884	6027	67	21

[a] Protein contains 15.5% N (Van Horn, 1997).

Table 12: Kilograms of P exported from the farm in milk in 1998.

Farm	Milk (kg)	Fat (kg)	4% FCM	P[a] (kg)	P/cow (kg)	P/ha (kg)
A	2818118	107088	2733574	2706	11	7
B	1662590	63178	1612712	1523	11	2
C	1778935	67600	1725567	1708	12	3
D	1150000	43700	1115500	1070	12	2
E	1696793	64478	1645889	1520	13	3
F	1079545	41023	1047159	1020	9	10
G	1196439	45465	1160546	1149	13	4

[a] Milk contains 0.099% P (NRC, 1989).

Table 13: Whole farm nutrient balance for farm A.

	Nitrogen (kg)		Phosphorus (kg)	
Inputs	1998	Post-change	1998	Post-change
Purchased feeds	33921.82	27733.64	6109.09	2646.36
Purchased feeds/cow	134.61	110.05	24.24	10.50
Purchased feeds/hectare	37.61	30.75	6.77	2.93
Bedding	200.91	200.91	1760.91	1760.91
Bedding/cow	0.80	0.80	6.99	6.99
Bedding/hectare	0.22	0.22	1.95	1.95
Atmospheric N from rain	541.82	541.82	0.00	0.00
Atmospheric N from rain/cow	2.15	2.15	0.00	0.00
Atmospheric N from rain/hectare	0.60	0.60	0.00	0.00
Purchased fertilizer	11480.00	11480.00	0.00	0.00
Purchased fertilizer/cow	45.56	45.56	0.00	0.00
Purchased fertilizer/hectare	12.73	12.73	0.00	0.00
Purchased cattle	0.00	0.00	0.00	0.00
Purchased cattle/cow	0.00	0.00	0.00	0.00
Purchased cattle/hectare	0.00	0.00	0.00	0.00
N fixation – legumes	0.00	0.00	0.00	0.00
N fixation – legumes/cow	0.00	0.00	0.00	0.00
N fixation – legumes/hectare	0.00	0.00	0.00	0.00
Total	46144.55	39956.36	7870.00	4407.27

	Nitrogen (kg)		Phosphorus (kg)	
Outputs	1998	Post-change	1998	Post-change
Milk	14414.55	14414.55	2706.36	2706.36
Milk/cow	57.20	57.20	10.74	10.74
Milk/hectare	15.98	15.98	3.00	3.00
Sold cattle	929.09	929.09	238.18	238.18
Sold cattle/cow	3.69	3.69	0.95	0.95
Sold cattle/hectare	1.03	1.03	0.26	0.26
Sold forages	0.00	0.00	0.00	0.00
Sold forages/cow	0.00	0.00	0.00	0.00
Sold forages/hectare	0.00	0.00	0.00	0.00
Sold manure	0.00	0.00	0.00	0.00
Sold manure/cow	0.00	0.00	0.00	0.00
Sold manure/hectare	0.00	0.00	0.00	0.00
Total	15343.64	15343.64	2944.55	2944.55

	Nitrogen (kg)		Phosphorus (kg)	
	1998	Post-change	1998	Post-change
Whole farm nutrient balance	30800.91	24612.73	4925.45	1462.73
Change in nutrient storage within farm system/cow	122.23	97.67	19.55	5.80
Change in nutrient storage within farm system/hectare	84.39	67.43	13.49	4.01
Net nutrient change within farm system after possible nutritional changes		(6188.18)		(3462.73)

Table 14: Whole farm nutrient balance for farm B.

	Nitrogen (kg)		Phosphorus (kg)	
Inputs	1998	Post-change	1998	Post-change
Purchased feeds	16499.09	29133.54	3063.64	2717.40
Purchased feeds/cow	117.01	203.73	21.73	19.00
Purchased feeds/hectare	8.24	14.56	1.53	1.36
Bedding	0.00	0.00	0.00	0.00
Bedding/cow	0.00	0.00	0.00	0.00
Bedding/hectare	0.00	0.00	0.00	0.00
Atmospheric N from rain	1201.82	1201.82	0.00	0.00
Atmospheric N from rain/cow	8.52	8.52	0.00	0.00
Atmospheric N from rain/hectare	0.60	0.60	0.00	0.00
Purchased fertilizer	30250.91	30250.91	10843.64	10843.64
Purchased fertilizer/cow	214.55	214.55	76.91	76.91
Purchased fertilizer/hectare	15.11	15.11	5.42	5.42
Purchased cattle	0.00	0.00	0.00	0.00
Purchased cattle/cow	0.00	0.00	0.00	0.00
Purchased cattle/hectare	0.00	0.00	0.00	0.00
N fixation – legumes	858.18	858.18	0.00	0.00
N fixation - legumes/cow	6.09	6.09	0.00	0.00
N fixation – legumes/hectare	0.43	0.43	0.00	0.00
Total	48810.00	61444.45	13907.27	13561.04

	Nitrogen (kg)		Phosphorus (kg)	
Outputs	1998	Post-change	1998	Post-change
Milk	8118.18	8118.18	1522.73	1522.73
Milk/cow	57.58	57.58	10.80	10.80
Milk/hectare	4.06	4.06	0.76	0.76
Sold cattle	1464.55	1464.55	444.55	444.55
Sold cattle/cow	10.39	10.39	3.15	3.15
Sold cattle/hectare	0.73	0.73	0.22	0.22
Sold forages	7556.36	7556.36	1601.82	1601.82
Sold forages/cow	53.59	53.59	11.36	11.36
Sold forages/hectare	3.78	3.78	0.80	0.80
Sold manure	0.00	0.00	0.00	0.00
Sold manure/cow	0.00	0.00	0.00	0.00
Sold manure/hectare	0.00	0.00	0.00	0.00
Total	17139.09	17139.09	3569.09	3569.09

	Nitrogen (kg)		Phosphorus (kg)	
	1998	Post-change	1998	Post-change
Whole farm nutrient balance	31670.91	44305.36	10338.18	9991.95
Change in nutrient storage within farm system/cow	224.62	314.22	73.32	70.86
Change in nutrient storage within farm system/hectare	39.10	54.70	12.76	12.34
Net nutrient change within farm system after possible nutritional changes		12634.45		(346.24)

Table 15: Whole farm nutrient balance for farm C.

	Nitrogen (kg)		Phosphorus (kg)	
Inputs	1998	Post-change	1998	Post-change
Purchased feeds	22600.00	17480.91	3663.64	2340.00
Purchased feeds/cow	153.74	111.34	24.92	14.90
Purchased feeds/hectare	16.45	12.72	2.67	1.70
Bedding	77.27	77.27	677.27	677.27
Bedding/cow	0.53	0.53	4.61	4.61
Bedding/hectare	0.06	0.06	0.49	0.49
Atmospheric N from rain	824.55	824.55	0.00	0.00
Atmospheric N from rain/cow	5.61	5.61	0.00	0.00
Atmospheric N from rain/hectare	0.60	0.60	0.00	0.00
Purchased fertilizer	7363.64	7363.64	0.00	0.00
Purchased fertilizer/cow	50.09	50.09	0.00	0.00
Purchased fertilizer/hectare	5.36	5.36	0.00	0.00
Purchased cattle	0.00	0.00	0.00	0.00
Purchased cattle/cow	0.00	0.00	0.00	0.00
Purchased cattle/hectare	0.00	0.00	0.00	0.00
N fixation – legumes	0.00	0.00	0.00	0.00
N fixation – legumes/cow	0.00	0.00	0.00	0.00
N fixation - legumes/hectare	0.00	0.00	0.00	0.00
Total	30865.45	25746.36	4340.91	3017.27

	Nitrogen (kg)		Phosphorus (kg)	
Outputs	1998	Post-change	1998	Post-change
Milk	10478.18	10478.18	1708.18	1708.18
Milk/cow	71.28	71.28	11.62	11.62
Milk/hectare	7.63	7.63	1.24	1.24
Sold cattle	1031.82	1031.82	265.45	265.45
Sold cattle/cow	7.02	7.02	1.81	1.81
Sold cattle/hectare	0.75	0.75	0.19	0.19
Sold forages	4079.09	4079.09	632.73	632.73
Sold forages/cow	27.75	27.75	4.30	4.30
Sold forages/hectare	2.97	2.97	0.46	0.46
Sold manure	0.00	0.00	0.00	0.00
Sold manure/cow	0.00	0.00	0.00	0.00
Sold manure/hectare	0.00	0.00	0.00	0.00
Total	15589.09	15589.09	2606.36	2606.36

	Nitrogen (kg)		Phosphorus (kg)	
	1998	Post-change	1998	Post-change
Whole farm nutrient balance	15276.36	10157.27	1734.55	410.91
Change in nutrient storage within farm system/cow	103.92	69.10	11.80	2.80
Change in nutrient storage within farm system/hectare	27.48	18.27	3.12	0.74
Net nutrient change within farm system after possible nutritional changes		(5119.09)		(1323.64)

Table 16: Whole farm nutrient balance for farm D.

	Nitrogen (kg)		Phosphorus (kg)	
Inputs	1998	Post-change	1998	Post-change
Purchased feeds	12309.09	754.55	2327.27	1107.27
Purchased feeds/cow	138.30	8.48	26.15	12.44
Purchased feeds/hectare	9.47	0.58	1.79	0.85
Bedding	22.73	22.73	0.91	0.91
Bedding/cow	0.26	0.26	0.01	0.01
Bedding/hectare	0.02	0.02	0.00	0.00
Atmospheric N from rain	868.18	868.18	0.00	0.00
Atmospheric N from rain/cow	9.75	9.75	0.00	0.00
Atmospheric N from rain/hectare	0.67	0.67	0.00	0.00
Purchased fertilizer	159.09	159.09	0.00	0.00
Purchased fertilizer/cow	1.79	1.79	0.00	0.00
Purchased fertilizer/hectare	0.12	0.12	0.00	0.00
Purchased cattle	0.00	0.00	0.00	0.00
Purchased cattle/cow	0.00	0.00	0.00	0.00
Purchased cattle/hectare	0.00	0.00	0.00	0.00
N fixation – legumes	1029.09	1029.09	0.00	0.00
N fixation – legumes/cow	11.56	11.56	0.00	0.00
N fixation - legumes/hectare	0.79	0.79	0.00	0.00
Total	14388.18	2833.64	2328.18	1108.18

	Nitrogen (kg)		Phosphorus (kg)	
Outputs	1998	Post-change	1998	Post-change
Milk	5703.64	5703.64	1070.00	1070.00
Milk/cow	64.09	64.09	12.02	12.02
Milk/hectare	4.39	4.39	0.82	0.82
Sold cattle	601.82	601.82	183.64	183.64
Sold cattle/cow	6.76	6.76	2.06	2.06
Sold cattle/hectare	0.46	0.46	0.14	0.14
Sold forages	0.00	0.00	0.00	0.00
Sold forages/cow	0.00	0.00	0.00	0.00
Sold forages/hectare	0.00	0.00	0.00	0.00
Sold manure	0.00	0.00	0.00	0.00
Sold manure/cow	0.00	0.00	0.00	0.00
Sold manure/hectare	0.00	0.00	0.00	0.00
Total	6305.45	6305.45	1253.64	1253.64

	Nitrogen (kg)		Phosphorus (kg)	
	1998	Post-change	1998	Post-change
Whole farm nutrient balance	8082.73	(3471.82)	1074.55	(145.45)
Change in nutrient storage within farm system /cow	90.82	(39.01)	12.07	(1.63)
Change in nutrient storage within farm system /hectare	15.37	(6.60)	2.04	(0.28)
Net nutrient change within farm system after possible nutritional changes		(11554.55)		(1220.00)

Table 17: Whole farm nutrient balance for farm E.

	Nitrogen (kg)		Phosphorus (kg)	
Inputs	1998	Post-change	1998	Post-change
Purchased feeds	15109.09	12000.91	3636.36	1466.36
Purchased feeds/cow	130.25	103.46	31.35	12.64
Purchased feeds/hectare	11.12	8.83	2.68	1.08
Bedding	584.55	584.55	5120.00	5120.00
Bedding/cow	5.04	5.04	44.14	44.14
Bedding/hectare	0.43	0.43	3.77	3.77
Atmospheric N from rain	816.36	816.36	0.00	0.00
Atmospheric N from rain/cow	7.04	7.04	0.00	0.00
Atmospheric N from rain/hectare	0.60	0.60	0.00	0.00
Purchased fertilizer	3888.18	3888.18	1480.91	1480.91
Purchased fertilizer/cow	33.52	33.52	12.77	12.77
Purchased fertilizer/hectare	2.86	2.86	1.09	1.09
Purchased cattle	0.00	0.00	0.00	0.00
Purchased cattle/cow	0.00	0.00	0.00	0.00
Purchased cattle/hectare	0.00	0.00	0.00	0.00
N fixation – legumes	0.00	0.00	0.00	0.00
N fixation – legumes/cow	0.00	0.00	0.00	0.00
N fixation - legumes/hectare	0.00	0.00	0.00	0.00
Total	20398.18	17290.00	10237.27	8067.27

	Nitrogen (kg)		Phosphorus (kg)	
Outputs	1998	Post-change	1998	Post-change
Milk	8258.18	8258.18	1520.91	1520.91
Milk/cow	71.19	71.19	13.11	13.11
Milk/hectare	6.08	6.08	1.12	1.12
Sold cattle	653.64	653.64	181.82	181.82
Sold cattle/cow	5.63	5.63	1.57	1.57
Sold cattle/hectare	0.48	0.48	0.13	0.13
Sold forages	0.00	0.00	0.00	0.00
Sold forages/cow	0.00	0.00	0.00	0.00
Sold forages/hectare	0.00	0.00	0.00	0.00
Sold manure	0.00	0.00	0.00	0.00
Sold manure/cow	0.00	0.00	0.00	0.00
Sold manure/hectare	0.00	0.00	0.00	0.00
Total	8911.82	8911.82	1702.73	1702.73

	Nitrogen (kg)		Phosphorus (kg)	
	1998	Post-change	1998	Post-change
Whole farm nutrient balance	11486.36	8378.18	8534.55	6364.55
Change in nutrient storage within farm system /cow	99.02	72.23	73.57	54.87
Change in nutrient storage within farm system hectare	20.88	15.23	15.52	11.57
Net nutrient change within farm system after possible nutritional changes		(3108.18)		(2170.00)

Table 18: Whole farm nutrient balance for farm F.

	Nitrogen (kg)		Phosphorus (kg)	
Inputs	1998	Post-change	1998	Post-change
Purchased feeds	19327.27	17439.09	2290.91	2045.45
Purchased feeds/cow	177.31	159.99	21.02	18.77
Purchased feeds/hectare	78.22	70.58	9.27	8.28
Bedding	0.00	0.00	0.00	0.00
Bedding/cow	0.00	0.00	0.00	0.00
Bedding/hectare	0.00	0.00	0.00	0.00
Atmospheric N from rain	142.73	142.73	0.00	0.00
Atmospheric N from rain/cow	1.31	1.31	0.00	0.00
Atmospheric N from rain/hectare	0.58	0.58	0.00	0.00
Purchased fertilizer	545.45	545.45	0.00	0.00
Purchased fertilizer/cow	5.00	5.00	0.00	0.00
Purchased fertilizer/hectare	2.21	2.21	0.00	0.00
Purchased cattle	0.00	0.00	0.00	0.00
Purchased cattle/cow	0.00	0.00	0.00	0.00
Purchased cattle/hectare	0.00	0.00	0.00	0.00
N fixation – legumes	0.00	0.00	0.00	0.00
N fixation - legumes/cow	0.00	0.00	0.00	0.00
N fixation - legumes/hectare	0.00	0.00	0.00	0.00
Total	20015.45	18127.27	2290.91	2045.45

	Nitrogen (kg)		Phosphorus (kg)	
Outputs	1998	Post-change	1998	Post-change
Milk	5354.55	5354.55	1020.91	1020.91
Milk/cow	49.12	49.12	9.37	9.37
Milk/hectare	21.67	21.67	4.13	4.13
Sold cattle	529.09	529.09	138.18	138.18
Sold cattle/cow	4.85	4.85	1.27	1.27
Sold cattle/hectare	2.14	2.14	0.56	0.56
Sold forages	0.00	0.00	0.00	0.00
Sold forages/cow	0.00	0.00	0.00	0.00
Sold forages/hectare	0.00	0.00	0.00	0.00
Sold manure	0.00	0.00	0.00	0.00
Sold manure/cow	0.00	0.00	0.00	0.00
Sold manure/hectare	0.00	0.00	0.00	0.00
Total	5883.64	5883.64	1159.09	1159.09

	Nitrogen (kg)		Phosphorus (kg)	
	1998	Post-change	1998	Post-change
Whole farm nutrient balance	14131.82	12243.64	1131.82	886.36
Change in nutrient storage within farm system/cow	129.65	112.33	10.38	8.13
Change in nutrient storage within farm system /hectare	141.32	122.44	11.32	8.86
Net nutrient change within farm system after possible nutritional changes		(1888.18)		(245.45)

Table 19: Whole farm nutrient balance for farm G.

	Nitrogen (kg)		Phosphorus (kg)	
Inputs	1998	Post-change	1998	Post-change
Purchased feeds	11818.18	6067.14	2254.55	0.00
Purchased feeds/cow	131.31	67.41	25.05	0.00
Purchased feeds/hectare	16.78	8.62	3.20	0.00
Bedding	2122.73	2122.73	522.73	522.73
Bedding/cow	23.59	23.59	5.81	5.81
Bedding/hectare	3.01	3.01	0.74	0.74
Atmospheric N from rain	695.45	695.45	0.00	0.00
Atmospheric N from rain/cow	7.73	7.73	0.00	0.00
Atmospheric N from rain/hectare	0.99	0.99	0.00	0.00
Purchased fertilizer	650.00	650.00	0.00	0.00
Purchased fertilizer/cow	7.22	7.22	0.00	0.00
Purchased fertilizer/hectare	0.92	0.92	0.00	0.00
Purchased cattle	15.45	15.45	3.64	3.64
Purchased cattle/cow	0.17	0.17	0.04	0.04
Purchased cattle/hectare	0.02	0.02	0.01	0.01
N fixation – legumes	0.00	0.00	0.00	0.00
N fixation - legumes/cow	0.00	0.00	0.00	0.00
N fixation - legumes/hectare	0.00	0.00	0.00	0.00
Total	15301.82	9550.78	2780.91	526.36

	Nitrogen (kg)		Phosphorus (kg)	
Outputs	1998	Post-change	1998	Post-change
Milk	2740.00	2740.00	522.73	522.73
Milk/cow	30.44	30.44	5.81	5.81
Milk/hectare	3.89	3.89	0.74	0.74
Sold cattle	525.45	525.45	151.82	151.82
Sold cattle/cow	5.84	5.84	1.69	1.69
Sold cattle/hectare	0.75	0.75	0.22	0.22
Sold forages	0.00	0.00	0.00	0.00
Sold forages/cow	0.00	0.00	0.00	0.00
Sold forages/hectare	0.00	0.00	0.00	0.00
Sold manure	0.00	0.00	0.00	0.00
Sold manure/cow	0.00	0.00	0.00	0.00
Sold manure/hectare	0.00	0.00	0.00	0.00
Total	3265.45	3265.45	674.55	674.55

	Nitrogen (kg)		Phosphorus (kg)	
	1998	Post-change	1998	Post-change
Whole farm nutrient balance	12036.36	6285.33	2106.36	(148.18)
Change in nutrient storage within farm system /cow	133.74	69.84	23.40	(1.65)
Change in nutrient storage within farm system /hectare	42.23	22.05	7.39	(0.52)
Net nutrient change within farm system after possible nutritional changes		(5751.04)		(2254.55)

Table 20: Comparisons of nutrients entering and leaving study farms.

Farm	N Inputs (kg)	N Outputs (kg)	Net Balance	N Inputs Exceed N Outputs by:
A	46145	15344	30801	3.0
B	48810	17139	31671	2.8
C	30865	15589	15276	2.0
D	14388	6305	8083	2.3
E	20398	8912	11486	2.3
F	20015	5884	14132	3.4
G	15302	3265	12036	4.7
			Average	2.9

Farm	P Inputs (kg)	P Outputs (kg)	Net Balance	P Inputs Exceed P Outputs by:
A	7870	2945	4925	2.7
B	13907	3569	10338	3.9
C	4341	2606	1735	1.7
D	2328	1254	1075	1.9
E	10237	1703	8535	6.0
F	2291	1159	1132	2.0
G	2781	675	2106	4.1
			Average	3.2

Table 21: Net nutrient excess as a percentage of nutrient inflows.

Farm	N inflows (kg)	Net excess (kg)	Percentage
A	46145	30801	66.7%
B	48810	31671	64.9%
C	30865	15276	49.5%
D	14388	8083	56.2%
E	20398	11486	56.3%
F	20015	14132	70.6%
G	15302	12036	78.7%
		Average	63.3%

Farm	P inflows (kg)	Net excess (kg)	Percentage
A	7870	4925	62.6%
B	13907	10388	74.7%
C	4341	1735	40.0%
D	2328	1075	46.2%
E	10237	8535	83.4%
F	2291	1132	49.4%
G	2781	2106	75.7%
		Average	61.7%

Table 22: Percentage difference between percentage inflows from NRC corrected rations and 1998 rations minus fertilizers.

Farm	Post Change N Inflows (kg)	Fertilizer (kg)	Net Inflows less Fertilizer (kg)	1998 N Inflows (kg)	1998 Inflows Less Fertilizer (kg)	Percentage Reduction due to Nutrition
A	39956	11480	28476	46145	34665	17.9%
B	61444	30251	31194	48810	18559	-68.1%
C	25746	7364	18383	30865	23502	21.8%
D	2834	159	2675	14388	14229	81.2%
E	17290	3888	13402	20398	16510	18.8%
F	18127	545	17582	20015	19470	9.7%
G	9551	650	8901	15302	14652	39.3%
					Average	17.2%

Farm	Post Change P Inflows (kg)	Fertilizer (kg)	Net Inflows less Fertilizer (kg)	1998 P Inflows (kg)	1998 Inflows Less Fertilizer (kg)	Percentage Reduction due to Nutrition
A	4407	0	4407	7870	7870	44.0%
B	13561	10844	2717	13907	3064	11.3%
C	3017	0	3017	4341	4341	30.5%
D	1108	0	1108	2328	2328	52.4%
E	8067	1481	6586	10237	8756	24.8%
F	2045	0	2045	2291	2291	10.7%
G	526	0	526	2781	2781	81.1%
					Average	36.4%

Table 23: Percentage of nutrients removed through milk and meat.

Farm	N inflows (kg)	Milk (kg)	Animal (kg)	Sum: Milk and Animals	Percentage
A	46145	14415	929	15344	33.3%
B	48810	8118	1465	9583	19.6%
C	30865	10478	1032	11510	37.3%
D	14388	5704	602	6305	43.8%
E	20398	8258	654	8912	43.7%
F	20015	5355	529	5884	29.4%
G	15302	2740	525	3265	21.3%
				Average	32.6%

Farm	P inflows (kg)	Milk (kg)	Animal (kg)	Sum: Milk and Animals	Percentage
A	7870	2706	238	2945	37.4%
B	13907	1523	445	1967	14.1%
C	4341	1708	265	1974	45.5%
D	2328	1070	184	1254	53.8%
E	10237	1521	182	1703	16.6%
F	2291	1021	138	1159	50.6%
G	2781	523	152	675	24.3%
				Average	34.6%

Table 24: Percentage of nutrients removed by milk, animals, and sold crops.

Farm	N inflows (kg)	Milk (kg)	Animal (kg)	Sold Crops (kg)	Sum: Milk, Animals, Sold Crops	Percentage
A	46145	14415	929	0	15344	33.3%
B	48810	8118	1465	7556	17139	35.1%
C	30865	10478	1032	4079	15589	50.5%
D	14388	5704	602	0	6305	43.8%
E	20398	8258	654	0	8912	43.7%
F	20015	5355	529	0	5884	29.4%
G	15302	2740	525	0	3265	21.3%
					Average	36.7%

Farm	P inflows (kg)	Milk (kg)	Animal (kg)	Sold Crops (kg)	Sum: Milk, Animals, Sold Crops	Percentage
A	7870	2706	238	0	2945	37.4%
B	13907	1523	445	1602	3569	25.7%
C	4341	1708	265	633	2606	60.0%
D	2328	1070	184	0	1254	53.8%
E	10237	1521	182	0	1703	16.6%
F	2291	1021	138	0	1159	50.6%
G	2781	523	152	0	675	24.3%
					Average	38.4%

Figure 1: Average Percent of Total N Imports from Off Farm Sources

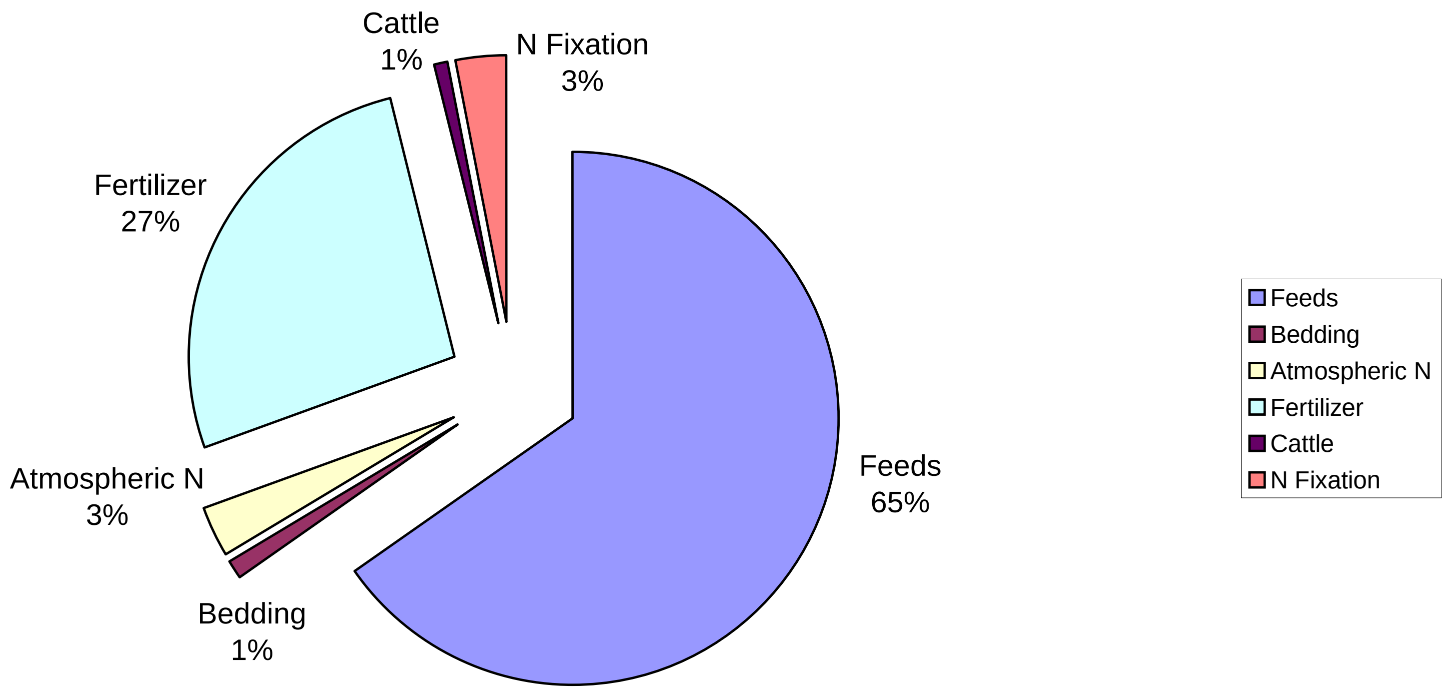


Figure 2: Average Percent of Total P Imports from Off Farm Sources

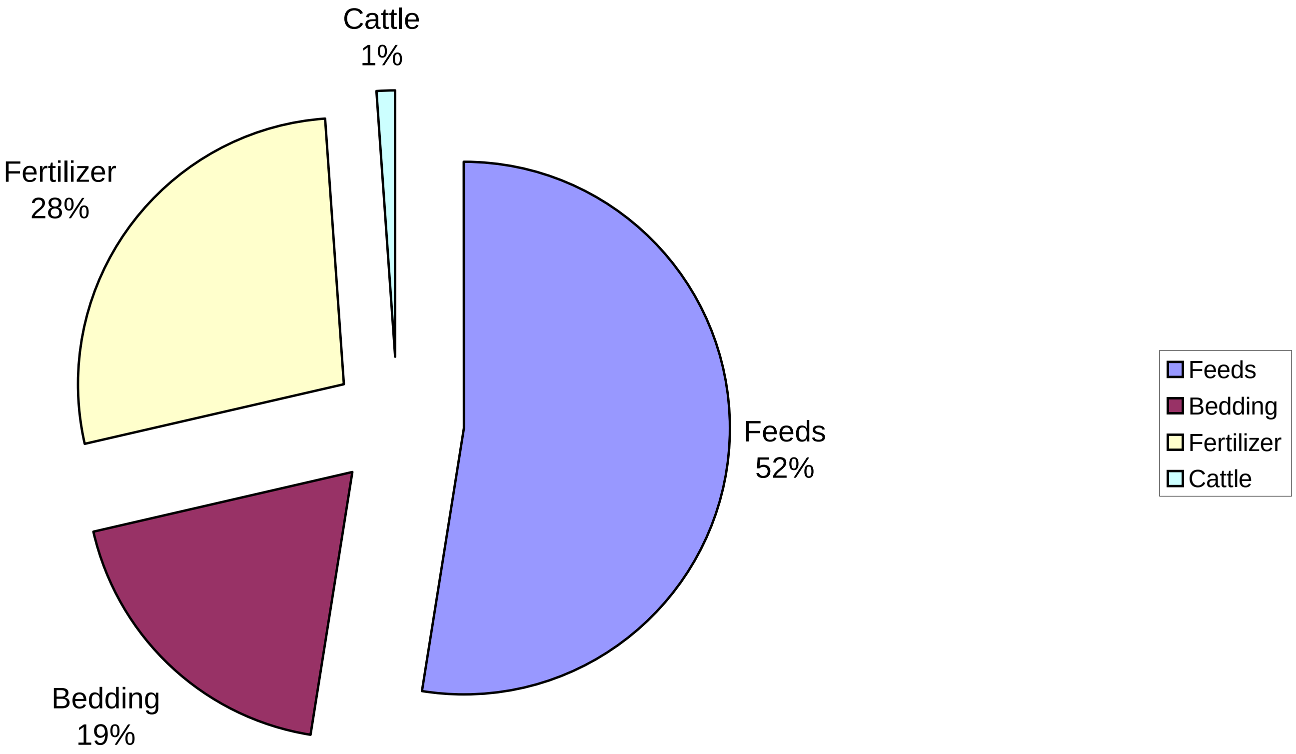


Figure 3: Average Percent of Total N Exports from Farm Sources

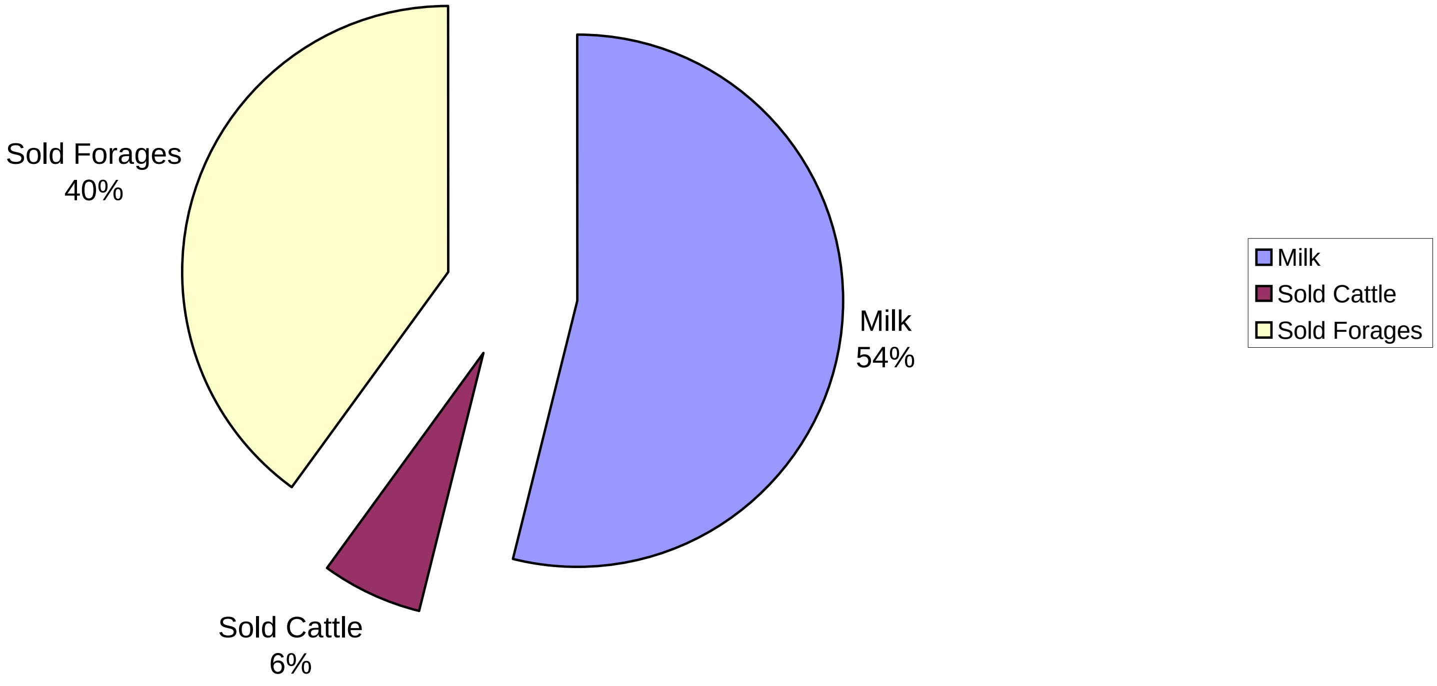


Figure 4: Average Percent of Total P Exports from Farm Sources

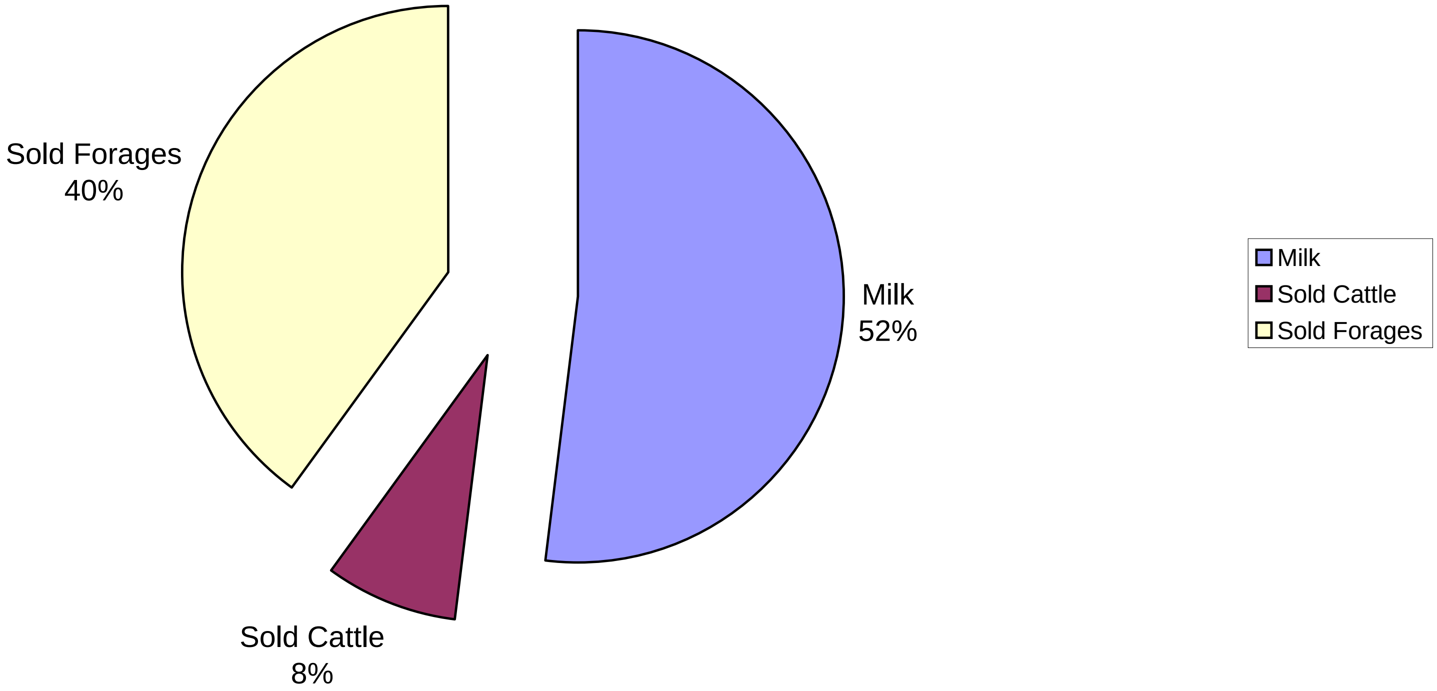
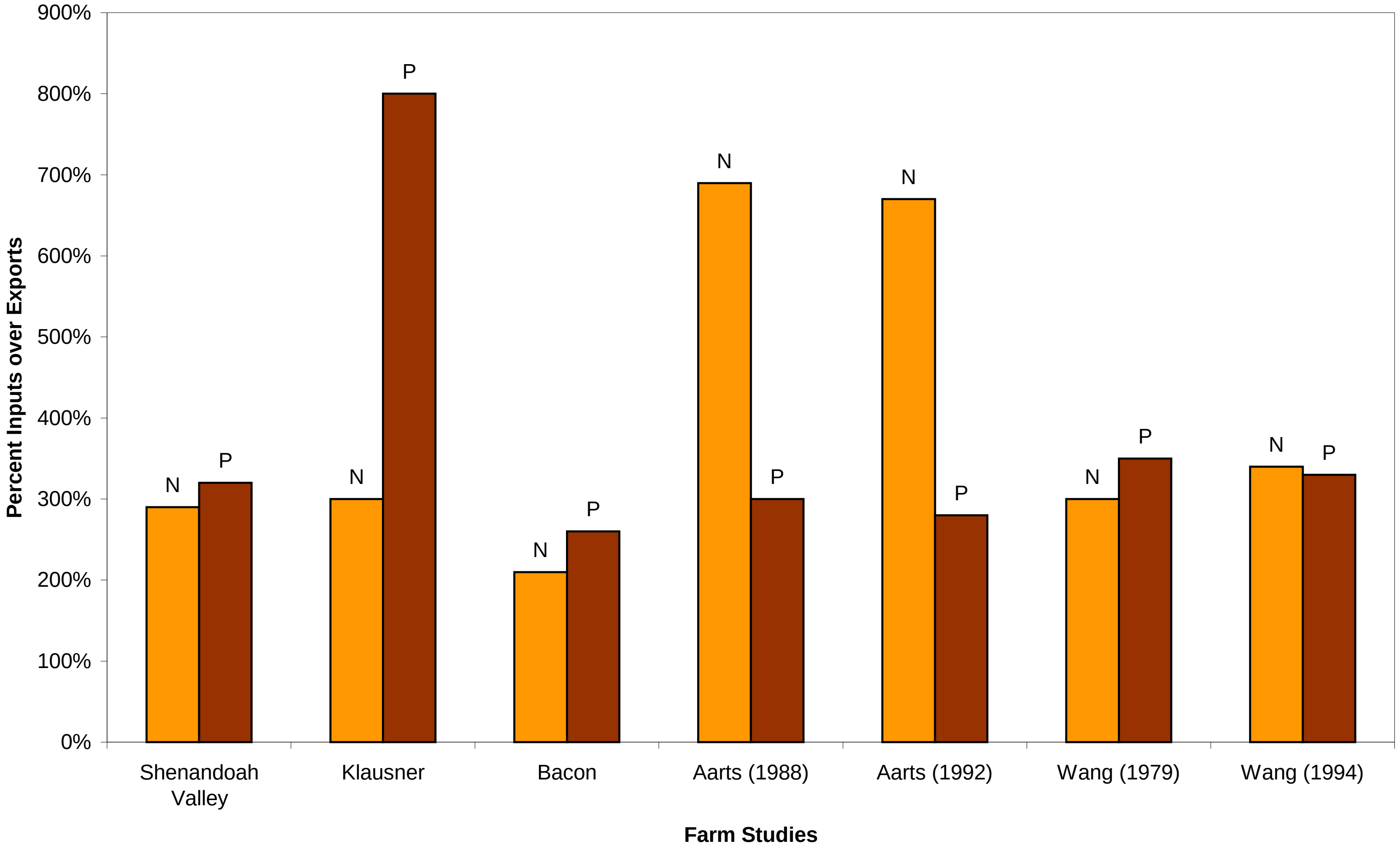


Figure 5: Multiple Study Comparison of Percent Inputs over Exports



Appendix Table 1: Statistical analysis of purchased feeds – N.

Purchased Feeds – N (kg)			
Farm	1998	Post Change	Difference
A	33921	27733	6188
B	16499	29133	-12634
C	22600	17480	5119
D	12309	754	11554
E	15109	12000	3108
F	19327	17439	1888
G	11818	6067	5750
Avg.	18797	15800	2996

P(T<=t) two-tail 0.33.

Appendix Table 2: Statistical analysis of purchased feeds/cow – N.

Purchased Feeds/Cow – N (kg)			
Farm	1998	Post Change	Difference
A	134	110	24
B	117	203	-86
C	153	111	42
D	138	8	129
E	130	103	26
F	177	159	17
G	131	67	63
Avg.	140	108	30

P(T<=t) two-tail 0.24.

Appendix Table 3: Statistical analysis of purchased feeds/ha – N.

Purchased Feeds/Ha – N (kg)			
Farm	1998	Post Change	Difference
A	37	30	6
B	8	14	-6
C	16	12	3
D	9	1	8
E	11	8	2
F	78	70	7
G	16	8	8
Avg.	25	20	4

P(T<=t) two-tail 0.06.

Appendix Table 4: Statistical analysis of total inputs – N.

Total N Input (kg)			
Farm	1998	Post Change	Difference
A	46144	39956	6188
B	48809	61443	-12634
C	30865	25746	5119
D	14388	2832	11555
E	20397	17289	3108
F	20015	18126	1889
G	15301	9550	5751
Avg.	27988	24991	2996

P(T<=t) two-tail 0.33.

Appendix Table 5: Statistical analysis of change in nutrient storage within farm system – N.

Change in Nutrient Storage – N (kg)			
Farm	1998	Post Change	Difference
A	30801	24613	6188
B	31670	44304	-12634
C	15277	10158	5119
D	8082	-3471	11554
E	11485	8377	3108
F	14131	12242	1889
G	12036	6285	5751
Avg.	17640	14644	2996

P(T<=t) two-tail 0.33.

Appendix Table 6: Statistical analysis of purchased feeds – P.

Purchased Feeds – P (kg)			
Farm	1998	Post Change	Difference
A	6109	2646	3462
B	3063	2717	346
C	3663	2340	1323
D	2327	1107	1220
E	3636	1466	2170
F	2290	2045	245
G	2254	0	2254
Avg.	3334	1759	1574

P(T<=t) two-tail 0.01.

Appendix Table 7: Statistical analysis of purchased feeds/cow – P.

Purchased Feeds/Cow – P (kg)			
Farm	1998	Post Change	Difference
A	24	10	14
B	21	19	2
C	24	14	10
D	26	12	14
E	31	12	19
F	21	18	3
G	25	0	25
Avg.	24	10	12

P(T<=t) two-tail 0.01.

Appendix Table 8: Statistical analysis of purchased feeds/ha – P.

Purchased Feeds/Ha – P (kg)			
Farm	1998	Post Change	Difference
A	6	2	4
B	1	1	0
C	2	1	1
D	1	1	0
E	2	1	1
F	9	8	1
G	3	0	3
Avg.	3	2	1

P(T<=t) two-tail 0.01.

Appendix Table 9: Statistical analysis of total inputs – P.

Total P Input (kg)			
Farm	1998	Post Change	Difference
A	7870	4407	3462
B	13907	13560	346
C	4340	3017	1323
D	2328	1108	1220
E	10237	8067	2170
F	2290	2045	245
G	2780	526	2254
Avg.	4821	4675	1574

P(T<=t) two-tail 0.01.

Appendix Table 10: Statistical analysis of change in nutrient storage within farm system – P.

Change in Nutrient Storage – P (kg)			
Farm	1998	Post Change	Difference
A	4926	1463	3462
B	10339	9992	346
C	1735	410	1324
D	1074	-145	1220
E	8535	6365	2170
F	1132	887	245
G	2107	-148	2255
Avg.	4264	2689	1574

P(T<=t) two-tail 0.01.

Appendix Table 11: Mean and standard deviation for 1998 data and post-change.

Variable	Mean (kg)	Standard Deviation (kg)	Mean (kg)	Standard Deviation (kg)
	1998	1998	Post-Change	Post-Change
N - Purchased Feeds	18798	7672	15801	10498
N - Purchased Feeds/Cow	140	20	109	63
N - Purchased Feeds/Hectare	63	63	52	59
N - Total Input	27989	14367	24992	19955
N - Change in Nutrient Storage	17641	9562	14644	15505
P - Purchased Feeds	3335	1369	1760	977
P - Purchased Feeds/Cow	25	3	12	6
P - Purchased Feeds/Hectare	10	7	6	7
P - Total Input	6251	805	4676	4657
P - Change in Nutrient Storage	4264	3799	2689	3935

Appendix Table 12: Mean and standard error for 1998 data and post-change.

Variable	Mean Difference of 1998 and Post Change (kg)	Standard Error of Mean Difference (kg)
N - Purchased Feeds	2996	2638
N - Purchased Feeds/Cow	31	23
N - Purchased Feeds/Acre	11	2
N - Total Input	2997	2638
N - Change in Nutrient Storage	2997	2638
P - Purchased Feeds	1575	400
P - Purchased Feeds/Cow	12	3
P - Purchased Feeds/Acre	4	0
P - Total Input	1575	400
P - Change in Nutrient Storage	1575	400

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