THE FATE OF MANURE PHOSPHORUS DURING PRODUCTION AND HARVEST OF TURFGRASS SOD

A Thesis

by

BRANDON TIEMAN MCDONALD

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2005

Major Subject: Agronomy

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Approved as to style and content by:

Donald M. Vietor (Co-Chair of Committee)	Richard H. White (Co-Chair of Committee)
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ABSTRACT

The Fate of Manure Phosphorus During Production and Harvest of

Turfgrass Sod. (May 2005)

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Co-Chairs of Advisory Committee: Dr. Richard H. White
Dr. Donald M. Vietor

Removal of manure from dairies to sites less prone to point-source nutrient pollution is an option for dealing with dairy confined animal feeding operation wastes. Applications of dairy manure waste to turfgrass sod can be an environmentally sound approach because both plant matter and soil are removed during harvest (Vietor et al., 2002).

Field scale research was conducted on a pair of adjacent, 1.42 ha Tifway bermudagrass fields on a fine-textured clay soil to investigate the fate of manure phosphorus (P) from composted dairy manure applications. Both fields received equal rates of supplemental nitrogen fertilizer but one was treated with composted dairy manure. The treated field received 75 kg ha^{-1} P during the first crop. After harvest, 127 kg ha^{-1} P was applied to the second crop. Once re-established, this crop was harvested.

Surface layer sod and subsurface soil were frequently sampled on a grid pattern from each field and analyzed to monitor soil P. Both plant extractable and total P analyses were used. It was determined that a sod harvest could

effectively remove all of the applied manure P. Below the sod layer, there were no increases in soil P as a result of the composted dairy manure treatments, indicating that P leaching did not occur.

Phosphorus runoff during rain events or irrigation was monitored by members of the Department of Biological and Agricultural Engineering. It was reported that more P was lost in runoff from the compost treated field than the untreated field.

Cumulative water infiltration rate, soil bulk density, and plant available water holding capacity of the soil were tested to determine if the composted dairy manure treatments affected these soil physical properties. The only significant change was an increase in plant available water holding capacity on the surface layer of the treated field.

An economic analysis was performed using actual financial data from the project. A scenario was created to investigate the feasibility of a dairy farm profitably adding a small turfgrass sod enterprise to its operation. It was determined that a sod field enterprise could be moderately to highly profitable for a dairy.

ACKNOWLEDGEMENTS

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CHAPTER I

INTRODUCTION

Dairy manure is an excellent source of mineral nutrients and organic carbon for turfgrass production in Texas. Many dairies in central Texas are confined feeding operations. A tremendous amount of wastes can accumulate over a short period of time. The total mineral nutrients available in manure and wastewater produced on CAFO's can exceed requirements of crops produced on surrounding land. Turfgrass sod production near CAFO's could enable export of manure or waste water sources of nutrients through annual harvests and increase manure or wastewater rates applied on land (Vietor et al., 2002). If manure or waste water is applied at rates limited to the P requirements of forage or feed crops, large land areas for application will be needed due to the large amount of manure produced on a CAFO and the small amount of P needed in many soils. Either fresh or composted dairy manure can be applied to turfgrass sod. In addition, turfgrass production can reduce erosion losses of soil and nutrients compared to row-crop agriculture because of a greater duration of vegetative cover. Research has also shown that manure applications to turfgrass can improve seedling establishment rate, soil pH, cation exchange

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capacity, particle aggregation, organic matter, and water content (Murray, 1981). In addition, bulk density can be reduced after manure applications (Vietor et al., 2002).

Objectives

There are four main research objectives:

1) Quantify P export through sod in relation to soil P and imports of manure P.
2) Correlate soil-test phosphorus levels with phosphorus concentrations and losses in runoff water.
3) Quantify chemical and physical properties of soil within and below the sod layer with and without composted dairy manure.
4) Develop enterprise budgets for sod production with and without composted dairy manure.

CHAPTER II

LITERATURE REVIEW

Introduction

Removal of manure from dairies for application on sites less prone to runoff is one option for managing manure sources of nutrients. House Bill 2699 imposed regulations that encouraged manure export from farms and watersheds near impaired water bodies to reduce P loading. Advisory committees joined together with regulatory agencies to establish criteria for total maximum daily loads (TMDL's) for P and other contaminants that impaired surface waters (Texas Natural Resource Conservation Commission, 2001). The wastewater lagoons, dry lots, and waste application fields of dairy CAFO's are potential point and non-point sources of P that are subject to the TMDL's and other regulations. Rain events large enough to produce significant runoff can carry nutrients from both point and non-point sources, which could be transported into the Upper North Bosque River. The Upper North Bosque River, in turn, transports the dissolved P to Lake Waco, which supplies drinking water to the city of Waco. There has been a great deal of attention given to this particular watershed because algal blooms and reduced water quality in lake Waco has been attributed to runoff from fields in the large dairy production region of Texas near Stephenville in the central part of the state. In this river system, the TMDL included a mandate for a 50% reduction in soluble reactive phosphorus entering the impaired segments of the Bosque River (Texas Natural Resource Conservation Commission, 2001).

In terms of impact on the environment, the use of raw or composted dairy manures for turfgrass sod production can have benefits over the use of commercial inorganic phosphate fertilizers. Gaudreau et al. (2002) reported that when equal amounts of P were surface applied as commercial inorganic fertilizer or composted dairy manure to turfgrass, losses of dissolved P (DP) were 58% less for the manure P than the commercial inorganic P.

Benefits of Turfgrass Use

Turfgrass sod pairs up well with the dairy industry because turfgrass is a high value crop. Greater value per hectare for turfgrass sod than for forages and row crops should make it more feasible for sod producers to afford the extra expense involved in shipping dairy manure to their farms. In addition, turfgrass sod removes more nutrients from a given hectare than typical row-crops (Vietor et al., 2002). This is because the surface layer of soil is removed along with the turfgrass during each harvest. The rapid development and maintenance of a dense population of plants in turfgrass also prevents the soil erosion problems that can occur in row-crop agriculture (Gross et al., 1991). In addition, manure application in sod production can improve re-growth rates of the sod fields and establishment of transplanted sod (Angle, 1994).

Composted vs. Fresh Dairy Manure

Dairy manure can either be applied to turfgrass as fresh or as composted manure. Several composting businesses in Erath County, Texas sell and deliver composted dairy manure. Composted manure has less odor problems, less volatilization losses of NH_3-N, and lower pathogenic microorganism counts than fresh manure (Vietor et al., 2002). However, incorporating fresh manure to a depth of 15 cm could prevent many of the problems associated with surface applications (Vietor et al., 2002). This type of incorporation might be performed during the seed bed preparation of a new sod field prior to seeding, sprigging, or the renovation of an existing sod field.

The N:P ratio of most manures make it difficult to meet all crop nitrogen needs through manure applications alone without causing excessive phosphorus loading on sites receiving manure over several years. In most cases where manures are used as a nutrient source, applications should be based on crop phosphorus requirements rather than on the nitrogen requirements. Most crops will show little or no economic response in yield or growth from additional P when soil-test phosphorus levels using the Bray-1 method exceed 50 ppm (Sharpley et al., 1993).

Both organic and inorganic compounds are present in dairy manure. As much as two-thirds of the total P found in the manure can be organic (Mikkelsen and Gilliam, 1995). Soil adsorption characteristics and mineralization rates for organic P compounds affect availability of manure P (Mikkelsen and Gilliam, 1995). Uncertainty about manure P forms and availability suggest dairy manure is more difficult to manage than inorganic P fertilizers (Gracey, 1984).

Phosphorus

Non-point source P losses from dairies are determined through two main factors: transport and source. The transport factors are rainfall and irrigation runoff and sediment loss. The source factors include soil P concentration and the methods, types, and rates at which supplemental P is applied (Sharpley et al., 1993). Though livestock manures contain all major and minor plant nutrients, nitrogen and phosphorus are of greatest concern in evaluation of source factors.

Phosphorus can be carried off site as either particulate phosphorus (PP) or as DP. Particulate P is the major form of P transported from tilled agricultural land, representing 75 to 90% of all P moved off-site (Schuman et al., 1973; Sharpley et al., 1987). Phosphorus movement in the particulate form occurs when P is adsorbed to soil and then erosion occurs from either an irrigation or rain event (Burwell et al., 1977; Garbrecht and Sharpley, 1992; Schuman et al., 1973). Particulate P is a variable source of P for algal uptake, with anywhere from 10 to 90% being bio-available (DePinto et al., 1981; Dorich et al., 1985; Sharpley et al., 1992). Dissolved P on the other hand can be more immediately available for algal uptake (Peters, 1981; Walton and Lee, 1972).

Application of dairy manure or wastewater to established turfgrass sod that has year-round vegetative cover will likely reduce PP movement compared to application of equal rates on row-crops. The dense plant population of grass plants in turf acts as a vegetative filter for soil particles suspended in water moving across the surface of the field. The processes of desorption, dissolution, and extraction from soil and plant matter within the turf surface must take place in order for PP movement through the turf to occur (Sharpley, 1985). In addition, Sharpley (1985) found that the conversion of PP to DP takes place near the soil surface as rain or irrigation water moves across the field. Dissolved reactive P concentrations greater than 0.05 mg/L can lead to eutrophication in surface waters.

Soil P concentration is normally quantified as soil-test phosphorus (STP) for agronomic purposes. Several laboratory methods are available to determine STP. Each method involves extracting all of the soluble P and a varying portion of the reactive P (Hansen et al., 2002). These laboratory methods include: Bray-1, Olsen, Mehlich-1, and Mehlich-3 (Hansen et al., 2002). Each of the STP methods have limitations as indicators of environmental risk because the forms of P extracted and measured are not necessarily related to runoff, leaching, or eutrophication. The extracted P forms do not necessarily affect and control P transport (Hansen et al., 2002). A better way to assess potential environmental impact from manure and soil P is P adsorption capacity and degree of P-saturation in soil (Hooda et al., 2000; Brooks et al., 1997; Sharpley, 1995). The degree of P-saturation is an expression of the percentage of the total P adsorption capacity occupied by P (Breeuwsma and Silva 1992).

Phosphorus Transport through Erosion and Runoff

Loading soil to P levels greater than plant growth requirements increases the likelihood for excessive P transport off of fields in runoff. Surface runoff occurs when rainfall or irrigation intensity exceeds water infiltration rate and the hydraulic conductivity of the soil (Mikkelsen and Gilliam, 1995). The risk of surface losses is greatest for the first rain event after a manure application and decrease for each following rain event (Edwards and Daniel 1994). The extent to which P is lost also decreases as the time between the application and runoff event increases (Sharpley, 1997).

It is important to realize that management practices can play a tremendous role in the runoff potential of a sod field. Management practices include timing of application, rates, incorporation methods, percent grass cover at the time of application, slope, and the source or type of manure (Hansen et al., 2002). Most of the phosphorus that leaves a field either as PP or DP comes from an interaction between the water and the top 0.04 to 0.12” of the soil (Sharpley, 1985). As much as 70% of P losses in runoff from a sod field can come from sediment-bound P (Sharpley and Smith, 1990). Because of this, manure application and accumulations of P near the soil surface are major factors in P runoff (Oloya and Logan, 1980; Sharpley et al., 1981). Similarly, runoff losses can be especially large immediately after a surface application of manure because of an initially high ratio of organic to inorganic forms of phosphorus in the manure. Two-thirds of manure P can be organic at the time of application (Mikkelsen and Gilliam, 1995). The high ratio of organic to inorganic P compounds initially present in the manure contributes to greater solubility and mobility of manure P until reactions with the soil have taken place and convert organic to inorganic P forms. The vulnerability of organic P to loss in runoff also increases without manure incorporation. With time, the organic forms of P in the manure will hydrolyze into inorganic phosphate forms of P (Mikkelsen and Gilliam, 1995).

Research was conducted on the turfgrass sod field used in this study, by faculty and graduate students in the Department of Biological and Agricultural Engineering at Texas A & M University. Runoff volume rates were measured and surface loss samples were collected during runoff events using automated sampling equipment (Choi et al., 2003). Runoff samples were filtered and then analyzed at the Texas A & M University Soil, Water, and Forage Testing Laboratory using inductively coupled plasma atomic emission spectrometry (ICP) to determine the levels of total phosphorus and other nutrients in runoff. Both the dissolved and sediment-bound or particulate fractions were analyzed. Choi (et al., 2003) focused on a time period from September 2002 to March 2003 (during the first sod crop) to quantify losses from the fields. Sixteen runoff events were sampled during this time period. The composted dairy manure treated field (75 kg ha-1 P applied) lost 5.303 kg ha^{-1} dissolved P and 1.065 kg ha^{-1} particulate P for a total of 6.368 kg ha^{-1} P. The untreated field (no compost) lost 3.034 kg ha^{-1} dissolved P and 0.546 kg ha^{-1} particulate P for a total of 3.580 kg ha^{-1} P. The difference of 2.820 kg ha^{-1} P between the fields is the amount of P lost during runoff that can be attributed to the composted manure application.

In addition to quantifying mass loss in runoff, Choi (et al., 2003) also compared soil-test P to total P losses in runoff. A linear relationship between increasing soil-test P and increasing P in runoff was noted.

Subsurface Transport of Phosphorus

Though surface losses of phosphorus tend to be of greatest concern after compost applications on agricultural lands, subsurface losses can occur and need attention. The high P adsorption capacity of most soils often causes sharp decreases in subsurface P even when P in surface layers is very high (Stamm et al., 1998). Phosphorus adsorption capacity in the surface and subsurface layers increases with clay content. Conversely, increasing sand content lowers P adsorption capacities. In addition, increasing Al, Fe, or Ca solubility can increase P adsorption capacity of a soil (Hansen et al., 2002). The high P adsorption capacity of most agricultural soils leads many researchers to think that subsurface movement of P is of little environmental concern (McBride, 1994). However, leaching of P can occur in soils that are sandy, acidic, or organic, and/or soils prone to macropore flow if STP values are elevated due to continuous application of livestock manures (Gachter et al., 1998; Heckwrath et al., 1995; Hooda et al., 1999).

Preferential flow is a transport mechanism where large amounts of water can be transferred through a small volume of soil. Examples include soil cracks, macropores, and fissures (Stamm et al., 1998). In preferential flow paths, water flow velocity is high and the ratio of sorptive surfaces to soil solution is low. Although many researchers suggest preferential flow can contribute to subsurface losses, little evidence exists to support this suggestion (Stamm et al., 1998). Sharpley et al. (1977) reported that high P loads in drainage water could be correlated with high soil P adjacent to drain tiles and not to high STP at the surface. This research further supports the idea that preferential flow is not the only mechanism by which P can move downward through the soil. Nevertheless, Stamm et al. (1998) demonstrates that preferential flow can be a mechanism of P transport, especially on soils that have received excessive rates of manure. Whether by worm burrows or soil cracks, subsurface P losses can occur and needs further investigation to quantify environmental impacts.

Nutrient Export

As previously mentioned, a great advantage to applying dairy manure to turfgrass is the potential to export 2 cm of soil and manure residue therein with the vegetative matter removed with each harvest. A much greater proportion of manure nutrients applied to the soil surface is removed from the sod than with aerial portions of row crops. Vietor et al. (2002) demonstrated P could be removed during harvest in rates proportional to the rates applied. For bermudagrass, 46% of manure P applied to small, replicated plots was removed at application rates as high as 200 kg P/ha/year. Yet sod growth rates and manure P export from large production-scale fields remains to be quantified.

Economics

Turfgrass sod can be a very agricultural profitable enterprise. Sod farms can see yearly returns to management of $1,968.00 per acre for a 100 acre farm up to $2,083.00 per acre by the fifth year of production (Cain et al., 2003). However, the initial capital investment can be prohibitive. According to Cain et al. (2003), per acre capital investments for a 100 acre farm can be $5,121.64 and $3,009.61 for a 1200 acre farm. In spite of high initial investment costs, many farmers have looked at turfgrass sod as an alternative to traditional crops because of the high profitability (Martin and Wells, 2001). According to Adrian (et al., 1995) bermudagrass is one of the most profitable warm season turfgrasses over a given time period to be used in sod production.

CHAPTER III

MANURE P IMPORT, EXPORT, AND EFFECTS ON SOIL PHYSICAL PROPERTIES

The environmental soundness of applying and cycling dairy manure and wastewater through turfgrass sod can be justified in both production and economic terms. First, turfgrass offers a complete ground cover that filters runoff and prevents transport of sediment and nutrients off-site. Second, turfgrass sod is unique with respect to greater potential amounts of manure phosphorus (P) removed in each harvest. In addition to vegetative plant parts, a thin (2 cm) layer of soil is removed during each sod harvest. This is important, especially for P, because harvesting a layer of soil with the crop removes greater percentages of applied manure P than harvest of aerial portions alone, only as in other crops (Vietor et al., 2002). Finally, the high value of turfgrass sod can help to offset production costs associated with dairy manure composting, hauling, and application.

Until now, little field scale work has been done to quantify amounts of applied manure P removed in turfgrass sod harvests. Phosphorus adsorption to soil particles can prevent leaching of surface applications of manure P through the soil profile, which keeps much of the manure P near the soil surface and available for export at harvest (Stamm et al., 1998). This is especially true of soils with high clay content (Hansen et al., 2002).

In addition to quantifying P removal at harvest, the effects of surface applications of composted dairy manure on soil physical properties need to be evaluated. Topdressings of compost could increase cumulative infiltration and plant available water holding capacity, while reducing bulk density in soil. Previous studies have only evaluated changes in these soil properties after manure was incorporated into the soil.

The two main objectives of this research are first, to quantify amounts of manure P removed in turfgrass sod harvests and second, to evaluate changes in cumulative infiltration, bulk density, and plant available water holding capacity after topdressing of composted dairy manure at rates up to 127 kg ha^{-1} P.

Materials and Methods

The research was conducted at the Texas A & M Agricultural Experiment Station in Burleson County beginning in June of 2002. The research site consisted of a pair of adjacent 1.42-ha fields (designated as treated or untreated) on a 0.9% slope of Ships clay (very fine, mixed, active, thermic Chromic Hapludert). A commercial planter was used to transplant 10-cm square plugs of Tifway bermudagrass (*Cynodon dactylon X Cynodon transvaalensis*) sod on 30-cm centers prior to sampling of soil and manure applications on each field. Turfgrass America, a commercial sod production company, provided the equipment, plugs, and labor for planting.

Composted dairy manure was topdressed on the treatment field when turfgrass reached approximately 50% coverage after planting and then again after the first sod harvest. Seventy-five kg ha^{-1} P was applied to the compost treated field for the first crop and 127 kg ha^{-1} P was applied for the second crop (APPENDIX, Table 1). Rates, dates, and methods of fertilizer N applications on fields were designed to simulate commercial sod production practices and promote rapid turfgrass growth. Equal rates of inorganic nitrogen fertilizer (21-0-0) were applied to each field, 394 kg ha^{-1} N for the first crop and 327 kg ha^{-1} N for the second crop. The treated field received composted dairy manure and the untreated field was the control.

Runoff from rainfall and irrigation events was collected on the western edge of each field in gutters that channeled water to H-flumes for automated measurements and sampling. The slope and surface drainage of each field were similar to commercial sod production fields. The plots were bordered and separated on all but the west end by 45-cm tall earthen dikes. The dikes confined surface runoff within each field for collection in the gutter system. Volumes and sediment and nutrient loads of runoff were quantified for each rainfall event (Choi et al., 2003).

Soil samples were taken from 12 locations distributed on a grid pattern within each field. A hydraulic soil probe (Giddings Machine Company, Ft. Collins, CO) was used to sample soil to a 90 cm depth at each grid point on dates before any composted manure applications and after each sod harvest.

Sampling was conducted on these dates to look at composted dairy manure effects before and after application for each crop. The cores were divided into depth intervals of 0 to 5 cm, 5 to 15 cm, 15 to 30 cm, 30 to 60 cm, and 60 to 90 cm. The 0 to 5 cm depth was of particular interest because most of the runoff losses of phosphorus originate from soil-water interaction within the 0.1 to 0.3 cm depth of soil (Sharpley, 1985). In addition to the core samples at grid points, soil was sampled from the 0 to 5 cm depth and composited from random locations in each field in coordination with dates of each major runoff event.

All soil, plant, and manure samples were analyzed by the Texas A & M University Soil, Water, and Forage Testing Lab. Analysis was performed to determine the amount of total and/or plant extractable nutrients in each sample. Total P analysis of soil and composted dairy manure was performed using Kjeldahl digestion (Parkinson and Allen, 1975). Plant-available P was extracted in acidified ammonium acetate–ethylenediamine tetraacetic acid (NH_4OAc-EDTA) (Hons et al., 1990). Both total P in digests and extractable soil P were measured through inductively-coupled optical emission spectroscopy (ICP).

Cumulative water infiltration rate, bulk density, and plant available water holding capacity of soil were measured to evaluate compost and turfgrass effects on soil physical properties. Cumulative infiltration was measured using 30.5 cm diameter x 12.5 cm tall x 1.59 mm thick steel infiltration rings driven 3-4 cm into the soil. A 6.5 cm x 100 cm PVC riser pipe with a small hose and valve located on the bottom was positioned near the infiltration ring. The ring was then filled with water to a depth that covered the turf canopy (approximately 3 to 4 cm in depth). At this point, a timer was started. Time (sec) and amount of water added was recorded and expressed per hour each time water from the riser pipe was added to the ring to maintain the water level. Cumulative infiltration readings were at locations on the grid pattern used for soil sampling. Cumulative infiltration was measured one month prior to the harvest of the first crop, one month after compost application, and one month prior to harvest of the second crop. These dates were selected in order to compare composted dairy manure affects with complete grass coverage for each crop (one month prior to harvest) as well as look at the effects of the compost shortly after application with partial grass coverage(one month after compost application). In addition, soil water content at each infiltration site was recorded.

Bulk density (*P*b) measurements were taken in conjunction with the dates in which 0 to 90 cm soil samples were taken. Bulk density was measured on each date soil was sampled to the 90 cm soil depth. Soil bulk density was computed as the quotient of oven dry weight divided by the volume of depth increments of each soil core sampled at the 12 grid locations. The inside diameter of the soil probe used to sample soil was 3.7 cm.

A ceramic plate moisture extraction apparatus was used to measure soil water content at field capacity and the wilting point. Procedures described by Klute (1986) were used. Soil samples were collected one month after composted dairy manure application during re-growth of the second sod crop while compost from the recent application was still visible on the soil surface. Plant available water holding capacity of the soil was computed as the difference between the field capacity (33.3 kPa) and permanent wilting point (1500 kPa). Soil samples were removed from 0 to 2.5 cm and 2.5 to 5.0 cm depths to separate the effects of the manure on the soil surface from depths out of contact with the manure layer.

Four 10 cm diameter plugs were sampled from each of the 12 grid points during harvest of each sod field. Sod samples were analyzed at the June 2003 harvest and then again at the November 2003 harvest. Soil was washed from the turf shoots and roots shortly after sampling. Plant and soil components were dried, ground, and analyzed to quantify the amounts of total and extractable P forms removed during sod harvest.

The Paired-T Tests of the Means Procedure was used for statistical analysis of effects of composted dairy manure on soil properties between fields (SAS Institute Inc., 2002). The two growth and harvest periods were treated as replications. The Analysis of Variance (ANOVA) Procedure was used to evaluate variations in soil sampled to the 90-cm depth before manure application and after each sod harvest. The General Linear Models (GLM) procedure was used to analyze variation of water infiltration rate. A P value ≤ 0.05 was regarded as significant.

Results and Discussion

Manure P Import/Export

Analyses of soil and plant components of 10-cm plugs were used to quantify phosphorus (P) export of turfgrass sod grown with and without composted dairy manure (Table 1). Total P analysis of the soil fraction of sod samples indicated that more P was removed in each sod harvest than was applied in manure. In addition, P was removed in the plant component of sod. The sum of soil P and total plant P removed in the first sod harvest from the treated field was 3.4 times greater than the P rate applied in composted manure. The second sod harvest removed 1.5 times more manure P than was applied.

The large total soil P content of fields before composted manure applications precluded significant differences in total P of harvested sod between treated and untreated fields for either harvest. In contrast, soil-test P in soil of sod harvested from the compost-treated field was greater (P=0.05) than from the untreated field at both harvests.

Soil Physical Properties

Compost application did not affect cumulative water infiltration and bulk density, but increases in plant available water holding capacity of the 0 to 2.5 cm depth of soil on the treated field were observed. Soil water content was similar each time cumulative water infiltration was measured. The lack of statistical differences (P=0.05) between fields or dates indicated antecedent soil water content was more determinant of water infiltration rate than topdressings of composted manure on turfgrass. Similar to water infiltration rate, bulk density did not vary (*P*=0.05) between fields or dates at the depths sampled. Yet, expected increases in *P*b were observed with increasing depth (*P*=0.05).

Topdressing of composted dairy manure did increase (*P*=0.05) plant-available water holding capacity in samples removed from the 0 to 2.5 cm depth increment during re-growth of the second sod crop. Plant available water holding capacity in this surface layer was 19.39% for soil sampled from the treated field and 18.25% for the untreated field. Within the 2.5 to 5.0cm depth, plant available water was 18.45% for the treated field and 17.89% for the untreated field. Yet, differences at the 2.5 to 5.0-cm depth were not significant (*P*=0.05). If the higher water-holding capacity of the treated field at the 0-2.5 cm depth is attributed to topdressing of composted dairy manure, a similar effect at depths below 2.5 cm would not be expected without incorporation of the compost.

Conclusions

The harvest of turfgrass sod can effectively remove P applied in composted dairy manure. Soil P present before composted manure applications can also be removed with sod as indicated by untreated field export data. The most significant observation is that more P was exported than imported.

Another important observation in this project was that significantly more soil-test P was exported from the compost treated field than the untreated field for each crop. This was not the case with total soil P, indicating that much of the manure P is in the plant-available form.

There was little observed change in cumulative water infiltration, bulk density, and plant available water holding capacity due to compost application. The application rates of composted dairy manure topdressed on turfgrass fields were not large enough to affect cumulative infiltration or bulk density. Topdressing of composted dairy manure during re-growth of the second sod crop increased plant available water holding capacity in the 0 to 2.5 cm layer, but not at deeper depths. Incorporation of composted manure is necessary for improvements in plant available water water-holding capacity at depths below the surface layer of soil.

CHAPTER IV

COMPOSTED DAIRY MANURE EFFECTS ON PHOSPHORUS THROUGH THE SOIL PROFILE

Accumulation of residual soil P is a major concern associated with repeated annual applications of raw or composted dairy manures during forage and row-crop production. In contrast to typical crop production practices, build up of manure P in soil is minimized during turfgrass sod production. In addition to harvest of plant material during sod harvests, a shallow layer of soil is removed. A substantial portion of the applied manure nutrients can be contained in this sod layer. Even after sod removal, P accumulation in soil below the harvested layer of sod could have negative, long-term environmental impacts.

Vietor et al., (2002) reported recovery of 46% to 77% of applied manure P in a single sod harvest from replicated plots on sandy soils topdressed with up to 200 kg ha^{-1} P $year^{-1}$. Increases in soil-test P below the harvested sod layer indicated the balance of applied P remained in plots. In contrast to the plot-scale studies on sandy soils, a substantial portion of Texas sod production occurs on fine-textured, clay soils. In addition, N fertilizer and irrigation rates on commercial sod fields are typically greater than those applied to the replicated plot studies (Vietor et al., 2002). Manure P export and losses during turfgrass sod production need to be quantified and evaluated under field-scale conditions similar to commercial sod production on fine-textured soils in Texas.

There are two main objectives of this part of the research. One is to determine whether or not phosphorus would accumulate in the surface layer of turfgrass sod when composted dairy manure is applied at rates of 75 kg ha^{-1} and 127 kg ha^{-1}. The second is to determine whether or not phosphorus will leach into and accumulate in the soil below the surface layer when composted dairy manure is applied to turfgrass sod.

Materials and Methods

The research was conducted at the Texas A & M Agricultural Experiment Station in Burleson County beginning in June of 2002. The research site consisted of a pair of adjacent 1.42-ha fields (designated as treated or untreated) on a 0.9% slope of Ships clay (very fine, mixed, active, thermic Chromic Hapludert). A commercial planter was used to transplant 10-cm square plugs of Tifway bermudagrass (*Cynodon dactylon X Cynodon transvaalensis*) sod on 30-cm centers prior to sampling of soil and manure applications on each field. Turfgrass America, a commercial sod production company, provided the equipment, plugs, and labor for planting.

Composted dairy manure was topdressed on the treatment field when turfgrass reached approximately 50% coverage after planting and then again after the first sod harvest. Seventy-five kg ha^{-1} P was applied to the compost treated field for the first crop and 127 kg ha^{-1} P was applied for the second crop (APPENDIX, Table 1). Rates, dates, and methods of fertilizer N applications on fields were designed to simulate commercial sod production practices and promote rapid turfgrass growth. Equal rates of inorganic nitrogen fertilizer (21-0-0) were applied to each field, 394 kg ha^{-1} N for the first crop and 327 kg ha^{-1} N for the second crop. The treated field received composted dairy manure and the untreated field was the control.

Runoff from rainfall and irrigation events was collected on the western edge of each field in gutters that channeled water to H-flumes for automated measurements and sampling. The slope and surface drainage of each field were similar to commercial sod production fields. The plots were bordered and separated on all but the west end by 45-cm tall earthen dikes. The dikes confined surface runoff within each field for collection in the gutter system. Volumes and sediment and nutrient loads of runoff were quantified for each rainfall event (Choi et al., 2003).

Soil samples were taken from 12 locations distributed on a grid pattern within each field. A hydraulic soil probe (Giddings Machine Company, Ft. Collins, CO) was used to sample soil to a 90 cm depth at each grid point on dates before any composted manure applications and after each sod harvest. Sampling was conducted on these dates to look at composted dairy manure effects before and after application for each crop. The cores were divided into depth intervals of 0 to 5 cm, 5 to 15 cm, 15 to 30 cm, 30 to 60 cm, and 60 to 90 cm. The 0 to 5 cm depth was of particular interest because most of the runoff losses of phosphorus originate from soil-water interaction within the 0.1 to 0.3 cm depth of soil (Sharpley, 1985). In addition to the core samples at grid points, soil was sampled from the 0 to 5 cm depth and composited from random locations in each field in coordination with dates of each major runoff event.

All soil, plant, and manure samples were analyzed by the Texas A & M University Soil, Water, and Forage Testing Lab. Analysis was performed to determine the amount of total and/or plant extractable nutrients in each sample. Total P analysis of soil and composted dairy manure was performed using Kjeldahl digestion (Parkinson and Allen, 1975). Plant-available P was extracted in acidified ammonium acetate–ethylenediamine tetraacetic acid (NH_4OAc-EDTA) (Hons et al., 1990). Both total P in digests and extractable soil P were measured through inductively-coupled optical emission spectroscopy (ICP).

The Paired-T Tests of the Means Procedure was used for statistical analysis of effects of composted dairy manure on soil properties between fields (SAS Institute Inc., 2002). The two growth and harvest periods were treated as replications. The Analysis of Variance (ANOVA) Procedure was used to evaluate variation of total and soil-test P in soil sampled to the 90-cm depth before manure application and after each sod harvest.

Results and Discussion

A main objective of this research was evaluate changes in total and soil-test P in the surface layer (0 to 5 cm) and depths below 5 cm after composted dairy manure applications during turfgrass sod production on a fine-textured soil. Changes in total and soil-test P within the 0 to 5 cm depth integrate effects of organic matter and nutrients applied in compost and growth of turfgrass (APPENDIX, Tables 2 and 3). Changes at depths below 5 cm are indicative of water percolation and leaching and transformation of nutrients from the surface layer since the compost was not incorporated into the soil (APPENDIX, Tables 4 and 5).

Total soil P in the 0 to 5 cm depth increased from before to after applications of composted dairy manure for each sod crop on the treated field (APPENDIX, Table 2). The mean increase due to manure application was 75% of the mean total P rates applied on the two sod crops. Yet, a comparison of total soil P between sampling dates after the second sod harvest and before manure application on the first sod crop indicated all of the applied manure P was exported with the sod layer removed in the two harvests (APPENDIX, Table 2). The reduction of total soil P (62 kg ha^{-1}) between dates spanning the two sod crops indicates “mining” of P occurred in the soil depth below the sod layer. The total P concentrations in soil sampled before re-growth of the second sod crop (June 10, 2004) could be outliers or overestimate soil total P for both treated and untreated fields. Variation of total soil P in the 0 to 5-cm depth of the untreated field supports the supposition that samples removed before manure application on the second crop yielded overestimates or outliers (APPENDIX, Table 2). The total soil P amounts measured during the first sod crop and after the second crop remained consistent on the untreated field. The large P content measured in soil at the start of the second sod crop occurred without application of P or other treatments.

Similar to total soil P, composted manure applications increased soil-test P on the treated field during production of both sod crops (APPENDIX, Table 3). The mean increase of soil-test P was 42% of the total P applied on the first sod crop and 67% of total P applied to the second crop. The percentage of inorganic P in composted dairy manure is typically greater than 60% and a large percentage of the inorganic P is water-soluble (Sharpley and Moyer, 2000). The increases in soil-test P after applications of manure could account for a large portion of the inorganic P in composted dairy manure applications. Similar to total P removal, sod harvests reduced soil-test P content in soil remaining below the sod layer to levels observed before manure application on the treated field. In addition, soil-test P content after the second sod harvest was 11% lower (not significant at P=0.05) than P content before manure was applied to the first sod crop.

Variation of soil-test P in the 0 to 5 cm depth of untreated field was similar to that for total P and fluctuated little during the course of both crops. Notice the untreated field value before re-growth of the second crop did not increase in relation to other sampling dates. This is a further indication that the, Table 2 (APPENDIX) value for total soil P preceding the second crop was erroneous, especially since both, Table 2 and Table 3 (APPENDIX) data came from the same soil samples on the respective dates.

Total and soil-test P concentrations within soil depth increments below 5 cm indicated whether or not P leached into or accumulated in the soil below the surface layer (APPENDIX, Tables 4 and 5). Analysis of variance (SAS, 2004) was used to compare total and soil-test P among depths sampled at the 12 grid points within each treated and untreated fields. A paired T Test (SAS, 2004) was used to compare treatments within each sampling date. Dates served as replications.

Mean total soil P at each depth in the compost treated field numerically decreased from the sampling date “before compost” (September 13, 2002) to the date “after harvest 2” date (November 10, 2003). Clearly, topdressing of manure P did not increase total soil P at depths below the harvested sod layer after either harvest date. In contrast, the reverse trend of total soil P over dates was observed at each depth of the untreated field. It is noteworthy that total soil P did not differ between treatments at each depth after either harvest, despite greater total soil P at all depths in the treated field before manure was applied. The unusually high mean total P at all depths of the untreated field “after harvest 1” coincide with the high values in the 0 to 5-cm depth in Table 2 (APPENDIX) for this field and date, further suggesting an error in lab analysis.

The trend of soil-test P over the three sampling dates was similar to total P (APPENDIX, Table 5). The difference in soil-test P between treated and untreated fields diminished after each sod harvest compared to the sampling date before manure applications. All but the 5 to 15 cm depth of the untreated field changed little over the two harvest dates of sod.

The compost used on the treatment field had a soil-test phosphorus (STP)/total phosphorus (TP) ratio of 0.49. This ratio was much higher than that of the soil on the research field. A comparison of the STP/TP ratio of the compost to the STP/TP ratio in the 0 to 5 cm layer of soil for both fields over time was used as an indicator of whether or not the compost applications increased the percentage of total phosphorus that was in the plant available or soil-test form (APPENDIX, Table 6). An increase of this ratio in the soil would be noteworthy because it has been demonstrated that there can be a direct relationship between soil-test P and P in runoff (Choi et al., 2003).

Though the treated field mean values appear higher after compost applications began, the difference was only significant for the two second crop dates. In fact, if an unusually high untreated field, second crop, before application total phosphorus value proved to be erroneous, the fields could potentially only be significantly different on one date. After the second harvest, the means for each field return to being very similar.

Conclusions

As long as sod is harvested after each manure application at phosphorus rates similar to this study on a fine-textured clay soil, the applied phosphorus will be effectively removed. Analyses of total and soil-test P at all depths indicate manure P does not leach from the harvested layer of sod grown in the fine-textured soil.

Topdressing of manure P on turfgrass sod fields at the rates used in this study will not be detrimental to soil or groundwater quality beneath the sod layer. Moreover, when manure P is applied to turfgrass sod at rates similar to this study and harvested at regular intervals, removal or “mining” of P from the antecedent soil P can occur.

The lack evidence for phosphorus leaching into the soil profile can be attributed, at least in part, to the soil type, moisture levels, and compost application methods. The soil is a *Ships* clay with approximately 33% clay content. Adsorption capacity increases with increasing clay content (Hansen et al., 2002). Due to the intensive growing practices of sod, whereby soil moisture levels must be kept high to insure adequate growth, the soil is rarely allowed to crack or develop fissures that would allow great preferential flow paths into the soil profile. These cracks or fissures can be a way for phosphorus leaching to occur (Gachter et al., 1998; Heckwrath et al., 1995; Hooda et al., 1999). Since the soil adsorptive capacity is high, preferential flow paths are the only likely means for P leaching. By not incorporating the composted dairy manure into the soil, the P stays on the surface and is more readily removed during the sod harvest. In addition, there is no conclusive evidence that composted dairy applications increased the ratio of soil-test P to total P below the sod layer.

According to the results of this study, composted dairy manure can be used in turfgrass sod production at P rates up to 125 kg ha^{-1} without causing environmental damage from accumulated manure P.

CHAPTER V

SOD FIELD ENTERPRISE FINANCIAL ANALYSIS

Handling manure waste can require modern equipment and facilities, be expensive, and be constrained by environmental regulations. Current manure management practices include long-term storage in lagoons, hauling from dairies to composting facilities, and land application for production of silage or hay crops near dairy facilities. A more profitable option for use of at least a portion of manure could be a turfgrass sod production enterprise at the dairy. The manure could be composted or applied raw. In either case, attention to nutrient loading is essential.

This integration of confined animal feeding operations (CAFO's) and turfgrass sod production could be feasible for several reasons. First, many dairies have land that could be converted from silage production into turfgrass production. Pasture land would not be a good prospect because of potential competition of the previous forage grass with the turfgrass sod. Second, if a dairy is using some portion of their available land for crop production, they will likely have access to irrigation water. Irrigation is a requirement for turfgrass sod production. Third, dairies typically own medium size tractors with hydraulic loaders for handling manure, feeding, and dairy maintenance activities. An existing inventory of equipment needed for sod production, such as tractors, will reduce the capital investment and depreciation costs allocated to the sod production enterprise. Finally, a small sod enterprise cannot sustain a full crew of laborers by itself. However, both labor and management costs can be shared between the turfgrass and dairy enterprises.

Methods

In order to analyze the feasibility of adding a turfgrass sod enterprise to a dairy, a scenario was created based on financial numbers generated during production of two crops of Tifway bermudagrass sod. Inputs and management practices for the two sod crops were similar to commercial sod production, which contributed to realistic estimates of investment and production costs for the sod enterprise in this scenario.

Land

It is assumed the dairy will own land used for the sod enterprise. For example, sod could be introduced on a field previously used to grow silage for the dairy cattle. Similar to the scale of the research field in this study, 7 acres or 2.84 hectares of a field used for silage production could be converted into turfgrass sod. Land rent will be charged to the sod enterprise at $125.00 per acre per crop. The dairy will likely have to purchase more silage, hay, or feed from an outside source to replace silage produced on land taken out of feed crop production. Previous studies in Virginia indicated the high profitability of turfgrass sod outweighed the cost of forage needed to replace production on land reallocated to turfgrass (Vietor et al., 2003). The soil (*Ships* clay) and slope (1%) of the research field is assumed identical to this production scenario. A custom operator will use specialized grass sprigging or plugging equipment to plant the Tifway bermudagrass. Planting cost is an item listed in Table 7 (APPENDIX).

Irrigation

Similar to the research field, it is assumed that irrigation water will come from a well previously used to irrigate the field. Installation costs for a larger pump needed to operate the irrigation system are included among capital investments for the field (APPENDIX, Table 7). In addition, a new hose reel will be purchased to provide over-head sprinkler rather than flood irrigation (APPENDIX, Table 7).

Equipment

It is assumed that the dairy has at least two tractors in the 50-100 horsepower range, with at least one having a front-end loader. The dairy also has a manure spreader for raw manure. In this scenario, raw manure scraped from the dairy dry lot will be used and applied through the manure spreader in place of composted manure. Sprayer equipment used for weed and insect control in silage will be used for the sod. In addition, it was assumed the equipment inventory of the dairy includes implements needed to prepare the land for the sod. The depreciation and maintenance cost of equipment borrowed from the dairy's inventory were allocated to Equipment Rental expense under operating expenses for each sod crop (APPENDIX, Tables 8 and 9). Rented items include: tractors, disks, field cultivator, land plane, tiller, box blade, and utility vehicle.

Several equipment items unique to turfgrass sod production will need to be purchased. Equipment costs for a sod harvester, all-terrain forklift, finishing mower, roller, and a used flatbed pickup were itemized for this scenario under capital investments (APPENDIX, Table 7). In addition, Internal Revenue Service (2003) depreciation rules were used to allocate equipment costs to each sod harvest.

Investment Costs

It is assumed that the total investment cost of $50,338.50 will be covered with a loan at 9% interest over a 10-year amortization period (APPENDIX, Table 7). The annual interest expense is allocated based on the time required to produce each sod crop (APPENDIX, Tables 2 and 3).

Return

Based on the time required to establish or re-grow a sod crop on the research field, it was assumed sod could be harvested once every 8 months or 1.5 harvests year^{-1}. From Lard (2001), an upper-end wholesale price of $1.00

yard^{-2} was assumed. Wholesale prices ranging from \$0.80-\$1.00 yard^{-2} are common for Tifway bermudagrass in the turfgrass industry. Both \$0.80 and \$1.00 yard^{-2} were used to compute gross revenue per area unit and per field (APPENDIX, Tables 8 and 9).

Expense Categories

The Operating Expenses (APPENDIX, Tables 8 and 9) are the variable costs of operating the sod enterprise. The labor figure is based upon a \$7.00 hourly wage. The number of hours required for the sod enterprise was estimated from Lard (2001) and maintenance records from the research field. Labor costs for the first sod crop (APPENDIX, Table 8) were greater than the second crop (APPENDIX, Table 9) due to labor required for land preparation, more frequent irrigation, weed control during establishment, and a longer growing period. Labor fringe represents Social Security payments of 6.2% and Medicare payments of 1.45% (IRS, 2003). In addition, worker's compensation insurance payments of \$9.50 per \$100.00 of wages plus a policy fee of \$150.00 per year were included in labor fringe. The annual policy fee was prorated to represent the eight month duration of each sod crop. Fuel, fertilizer, and chemical costs are based on costs incurred for the research field. Equipment Rental expense for the research field comprised equipment leases from a local equipment dealer and daily rental charges for equipment provided by either Texas Agricultural Experiment Station Farm Services or rental companies.

Electricity expense was estimated from monthly operating charges for the electric irrigation well pump used on the research field. Parts and Supplies expenses were assumed to be equal to those incurred during management of the research field. Similarly, miscellaneous expense for the dairy scenario is set equal to that for each sod crop produced during the research project, but soil analysis fees related to the soil nutrient research in this project were partially excluded. This is because a sod producer would not need to perform such extensive or costly soil analysis. .

The Capital Expenses category represents fixed costs of operation (APPENDIX, Tables 8 and 9) calculated for the eight months required to produce each sod crop. Interest expense for the eight-month duration of each crop is based upon the total investment cost of $50,338.50 covered with a loan at 9% interest for a 10-year amortization period. The expenses listed for equipment, irrigation pump, irrigation pipe, and planting are depreciation costs for capital expenditures (APPENDIX, Tables 8 and 9).

Harvesting, Marketing, and Business expenses were classified as Other Expenses, separate from Operating and Capital Expenses. These other expenses were estimated per sod crop from Lard (2001). The sum of Operating, Capital, and Other Expenses, presented as Total Expenses, was compared to potential revenue for each sod crop (APPENDIX, Tables 8 and 9) . The estimates of total revenue are based on the assumption that sod harvests are not 100% efficient. Although each acre could yield 4840 yd^2, only 4100 yd^2 are assumed harvestable (Lard, 2001). Harvest inefficiencies include “ribbons” of un-harvested turfgrass left between each strip of harvested sod to allow faster re-growth, deferred harvest of immature areas, and obstructed access to certain areas of the field because of irrigation wells or other objects. Total revenue was calculated for two selling prices, \$0.80 yd^{-2} and \$1.00 yd^{-2}. Breakeven figures for each crop were also included. Net income was computed as Total Revenue minus Total Expenses for both sod prices.

Results and Discussion

This analysis is unique because it involves adding one agricultural enterprise to another existing agricultural enterprise. Much of the previous financial analysis work involving turfgrass sod production has been done by focusing on the sod enterprise as a stand alone business rather than an extension of another. However, analysis performed by others still has relevance for comparison.

For purposes of comparison, four other studies were reviewed: Economic Feasibility of Turfgrass-Sod Production by Adrian, Loyd, and Duffy (1995), Turfgrass-Sod Production in Alabama: Economics and Marketing by Cain, Adrian, Duffy, and Guertal (2003), New Organic Production Method for Hybrid Bermudagrass, Estimated Costs per Acre and Per Square Yard by Lard (2001), and Economics of Turfgrass Establishment by Martin and Wells (2001).

All had data for a 100 acre sod farm with the exception of Martin and Wells (2001), who performed analysis on a 40 acre farm. The larger size of these operations compared to the 7 acre dairy farm enterprise allows for greater economies of scale. Each had revenue data for bermudagrass sod sold at \$1.00 yd^{-2} as well as establishment costs.

The major ways in which the dairy farm scenario is different from the other analyses are: smaller size, connectivity to another enterprise, single turfgrass species rather than multiple species grown, percent harvestable sod per acre estimations, production timescale for establishment and re-establishment after each harvest, and finally two of the others were on a per year basis rather than a per crop basis as with this study.

All but Lard (2001) looked at the use of other turfgrass species such as zoysiagrass or centipedegrass in addition to bermudagrass. Harvestable sod per acre estimations ranged from 3800 yd^2 (Martin and Wells, 2001) to 4100 yd^2 (Cain et al., 2003). Cain et al. (2003) used an establishment period of 9 months and a re-establishment period of 6.8 months. Adrian et al. (1995) used an establishment period of 10 months and a re-establishment period of 4 to 6 months. Martin and Wells (2001) estimated establishment to take 3 to 4 months. The dairy farm scenario had only Tifway bermudagrass, a 4100 yd^2 per acre harvestable estimation, and a twelve month establishment period and a 5 month re-establishment period. Each of these differences contributed to different cost and revenue figures.

Refer to Table 10 (APPENDIX) for establishment crop cost, revenue, and profit comparison information between analyses. It is important to keep in mind that accurate comparisons are difficult due to inconsistencies in the way each analysis was performed. However, the dairy farm scenario appears to be competitive with the other analyses in spite of the differences.

Neither cost savings related to manure disposal for the dairy nor commercial fertilizer savings are accounted for in the analysis. The cost of hauling manure off the dairy to composting facilities could be substantially larger than costs of application to the turf field. A more detailed analysis of potential cost sharing for manure and wastewater disposal, labor, marketing and business, and other expense categories could reveal additional economic benefits of turfgrass sod production near dairy CAFO's.

Conclusions

Based upon the given scenario and assumptions made, it could be moderately to highly profitable for a dairy to operate a small turfgrass sod production field in combination with the dairy. Estimated costs and revenues (APPENDIX, Tables 8 and 9) for the initial and second crop indicate profitability if the sod is sold for \$1.00 yd^{-2}. At the \$0.80 yd^{-2} selling price, a loss is reported for the initial crop but improves significantly for the second crop

There are many variable costs and great flexibility in the capital expense category, which would enable an operator to increase profit or incur greater loss.

The opportunity for a profitable sod enterprise in conjunction with a dairy appears feasible and deserves further investigation. Manure-grown sod can expand and diversify the earning potential of dairy CAFO's.

CHAPTER VI

DISCUSSION AND CONCLUSIONS

Discussion

Composted dairy manure can be an environmentally sound component of a turfgrass sod production system if handled properly. With increasing pressure on dairies to more carefully manage manure nutrients, applications to turfgrass sod should be considered. The high value of turfgrass per acre in comparison with more traditional crops can help offset added costs of manure applications. By removing soil and plant material during a sod harvest, more nutrients can be removed than with a more traditional crop where only the aerial portions of the plant are harvested (Vietor et al., 2002). Composted dairy manure used in a turfgrass sod production system also provides supplemental nutrients and organic matter, likely improving turfgrass performance. Additional analysis was performed to determine if a dairy to could establish a small sod field on-site to dispose of some manure and make a profit at the same time.

Objectives

This research study had four main objectives:

1) Quantify P export through sod in relation to soil P and imports of manure P.

2) Correlate soil-test phosphorus levels with phosphorus concentrations and losses in runoff water.
3) Quantify chemical and physical properties of soil within and below the sod layer with and without composted dairy manure.
4) Develop enterprise budgets for sod production with and without composted dairy manure.

Conclusions

Objective 1

The harvest of turfgrass sod can effectively remove P applied in composted dairy manure, as well as soil P present before composted manure applications can be exported in the layer of soil removed with sod. The most significant observation is that more P was exported than imported.

Another important observation in this project was that significantly more soil-test P was exported from the compost treated field than the untreated field for each crop. This was not the case with total soil P, indicating that much of the manure P is in the plant available form.

As long as sod is harvested after each manure application at phosphorus rates similar to this study on a fine-textured clay soil, the applied phosphorus will be effectively removed. Analyses of total and soil-test P at all depths indicate manure P does not leach from the harvested layer of sod grown in the fine-textured soil.

Refer to Table 1 (APPENDIX) for data related to this objective.

Objective 2

Research was conducted on the turfgrass sod field used in this study, by faculty and graduate students in the Department of Biological and Agricultural Engineering at Texas A & M University. The composted dairy manure treated field (75 kg ha^{-1} P applied) lost 5.303 kg ha^{-1} dissolved P and 1.065 kg ha^{-1} particulate P in runoff water for a total of 6.368 kg ha^{-1} P. The untreated field (no compost) lost 3.034 kg ha^{-1} dissolved P and 0.546 kg ha^{-1} particulate P in runoff water for a total of 3.580 kg ha^{-1} P. The difference of 2.820 kg ha^{-1} P between the fields is the amount of P lost during runoff that can be attributed to the composted dairy manure application.

In addition to quantifying mass loss in runoff, Choi (et al., 2003) also compared soil-test P to total P losses in runoff. A linear relationship between increasing soil-test P and increasing P in runoff was noted. There is no conclusive evidence that composted dairy applications increased the ratio of soil-test P to total P.

Phosphorus runoff from composted dairy manure treated sod fields can be a problem as indicated by this recent research. However, proper management and application practices can minimize environmental risks. Management practices that can lessen likelihood for manure nutrient runoff include proper timing of application, avoiding excessive rates, including soil incorporation methods, having adequate percent of grass cover at the time of application, avoiding application to steep slopes, and giving attention to the source or type of manure (i.e. nutrient content) (Hansen et al., 2002).

Refer to Table 6 (APPENDIX) for data related to this objective.

Objective 3

This study produced little evidence to suggest that phosphorus leached into the soil profile. The soil is a *Ships* clay with approximately 33% clay content. Adsorption capacity increases with increasing clay content (Hansen et al., 2002). Due to the intensive growing practices of sod, whereby soil moisture levels must be kept high to insure adequate growth, the soil is rarely allowed to crack or develop fissures that would allow great preferential flow paths into the soil profile. These cracks or fissures can be a way for phosphorus leaching to occur (Gachter et al., 1998; Heckwrath et al., 1995; Hooda et al., 1999). Since the soil adsorptive capacity is high, preferential flow paths are the only likely means for P leaching. By not incorporating the composted dairy manure into the soil, the P stays on the surface and is more readily removed during the sod harvest.

Topdressing of manure P on turfgrass sod fields at the rates used in this study will not be detrimental to soil or groundwater quality beneath the sod layer. Moreover, when manure P is applied to turfgrass sod at rates similar to this study and harvested at regular intervals, removal or “mining” of P from the antecedent soil P can occur.

According to the results of this study, composted dairy manure can be used in turfgrass sod production at P rates up to 125 kg ha^{-1} without causing environmental damage from accumulated manure P.

There was little observed change in cumulative water infiltration, bulk density, and plant available water holding capacity. The application rates of composted dairy manure topdressed on the treated field were not large enough to affect cumulative infiltration or bulk density. Topdressing of composted dairy manure during re-growth of the second sod crop increased plant available water holding capacity in the 0 to 2.5 cm layer, but not at deeper depths. Incorporation of composted manure is necessary for improvements in plant available water holding capacity at depths below the surface layer of soil.

Refer to Tables 2, 3, 4, and 5 (APPENDIX) for data related to this objective.

Objective 4

Based upon the given scenario and assumptions made, it could be moderately to highly profitable for a dairy to operate a small turfgrass sod production field in combination with the dairy. Estimated costs and revenues (APPENDIX, Tables 8 and 9) for the initial and second crop indicate profitability if the sod is sold for \$1.00 yd^{-2}. At the \$0.80 yd^{-2} selling price, a loss is reported for the initial crop but improves significantly for the second crop

There are many variable costs and great flexibility in the capital expense category, which would enable an operator to increase profit or incur greater loss. The opportunity for a profitable sod enterprise in conjunction with a dairy appears feasible and deserves further investigation. Manure-grown sod can expand and diversify the earning potential of dairy confined animal feeding operations (CAFO).

Refer to Tables 7, 8, 9, and 10 (APPENDIX) for data related to this objective.

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APPENDIX

TABLES

Table 1. Phosphorus Export Through Bermudagrass Sod

	Manure P Applied	Soil P Exported		Plant P Exported
Treatment	**Total P**	**Total P**	**Soil-Test P**	**Total P**
First Sod Crop	----------------------------------	kg ha^{-1}	--------------------------------------	
Compost Treated	75	207	68*	47
Untreated	----	182	39	45
Second Sod Crop	------------------------------------	kg ha^{-1}	---------------------------------------	
Compost Treated	127	159	75*	37*
Untreated	----	136	31	23

* denotes significant difference at the 0.05 level between treatments
-All phosphorus values are on a dry weight basis.
-Analyzed using the MEANS procedure(paired T-TEST comparison)

Table 2. Total Soil Phosphorus Levels in the 0 to 5 cm Layer before and after Composted Dairy Manure Applications to Bermudagrass Sod

Treatment	Before Application	After Application
First Sod Crop	-----------------------kg ha^{-1}-----------------------	
Compost Treated	426*	518*
Untreated	335	327
Second Sod Crop	-----------------------kg ha^{-1}-----------------------	
Compost Treated	416	469* (364†)
Untreated	451	342 (357)

* denotes significant difference at the 0.05 level between treatments
† denotes significant difference at the 0.05 level between 9/13/02 and 11/10/03 data values.
() indicates data from soil samples taken on 11/10/02 after the second sod harvest
-Data was analyzed using the MEANS procedure(paired T-TEST comparison).
-The dates on which the samples were taken are as follows: first crop, before application=9/13/02, after application=5/1/03; second crop, before application=6/10/03, after application=9/16/03.

Table 3. Soil-Test Phosphorus Levels in the 0 to 5 cm Layer before and after Composted Dairy Manure Applications to Bermudagrass Sod

Treatment	Before Application	After Application
First Sod Crop	---kg ha^{-1}	---------------------------------------
Compost Treated	103*	134*
Untreated	87	85
Second Sod Crop	---kg ha^{-1}	---------------------------------------
Compost Treated	108*	193* (92)
Untreated	80	86 (85)

* denotes significant difference at the 0.05 level between treatments
() indicates data from soil samples taken on 11/10/02 after the second sod harvest
-Data was analyzed using the MEANS procedure(paired T-TEST comparison).
-The dates on which the samples were taken are as follows: first crop, before application=9/13/02, after application=5/1/03; second crop, before application=6/10/03, after application=9/16/03.

Table 4. Total Phoshorus Main Effects below the Surface Layer by Sampling Date

		Before Compost		After Harvest 1		After Harvest 2	
		Treated	Untreated	Treated	Untreated	Treated	Untreated
		---------- mg kg^{-1} ----------					
Depth	5-15 cm	521a*	393a	478a	495a	402a	443a
	15-30 cm	419b*	331b	445ab	474a	359a	389b
	30-60 cm	407b*	303bc	417bc	451a	365a	382b
	60-90 cm	410b*	291c	382c*	465a	392a	354c

* indicates significant differences between treatments at the 0.05 level
-Data within each treatment was analyzed by depth using the ANOVA procedure. Comparisons within each replication(date) between treatments at each depth was performed using MEANS procedure(paired T-TEST comparison).
-The dates on which the samples were taken are as follows: before compost=9/13/02, after harvest 1=6/10/03, and after harvest 2=11/10/03.

Table 5. Soil-Test Phoshorus Main Effects below the Surface Layer by Sampling Date

		Before Compost		After Harvest 1		After Harvest 2	
		Treated	**Untreated**	**Treated**	**Untreated**	**Treated**	**Untreated**
		mg kg^{-1}					
Depth	**5-15 cm**	120a*	97a	109a*	91a	91a	92a
	15-30 cm	61b*	53b	60b	55b	55b	60b
	30-60 cm	48c	45c	50c*	45c	48b	52c*
	60-90 cm	44c	40c	47c*	43c	63b	49c

* indicates significant differences between treatments at the 0.05 level
-Data within each treatment was analyzed by depth using the ANOVA procedure. Comparisons within each replication(date) between treatments at each depth was performed using MEANS procedure(paired T-TEST comparison).
-The dates on which the samples were taken are as follows: before compost=9/13/02, after harvest 1=6/10/03, and after harvest 2=11/10/03.

Table 6. Soil-Test Phosphorus/Total Phosphorus Ratios (0 to 5 cm) Corresponding to Composted Dairy Manure Applications

Production cycle	Sampling	Treated	Untreated
1st crop	Before application	.242 (.028)	.261 (.029)
	After application	.264 (.043)	.256 (.029)
2nd crop	Before application	.261 (.023)	.179 (.022)
	After application	.408 (.052)	.253 (.019)
	After harvest	.253 (.026)	.240 (.013)

() indicates standard deviation of mean of sampling points on field grid
-The dates on which the samples were taken are as follows: first crop, before application=9/13/02, after application=5/1/03; second crop, before application=6/10/03, after application=9/16/03, after harvest=11/10/04.

Table 7. Capital Investments

*Years	Item	Cost	†Crops	Cost Harvest^{-1}
	Planting Costs			
5	Planting	$1963.50	7.5	$261.80
	Equipment Costs			
5	1980 Chevrolet 1-ton, flatbed pickup	$1500.00	7.5	$200.00
10	Used Brouwer, tractor-mounted slab harvester	$15,000.00	15	$1000.00
10	Used Spyder all-terrain diesel forklift	$12,000.00	15	$800.00
10	New Kifco hose reel	$6500.00	15	$433.33
10	Rhino 100” 3-pt. finishing mower	$2875.00	15	$191.67
10	7’ wide, 52” steel sod roller	$3500.00	15	$233.33
Equipment Costs Total		*$41,375.00*		*$2858.33*
	Irrigation Pump & Pipe			
20	4” submersible irrigation pump, pipe, risers	$7000.00	30	$233.33
	Total Costs	**$50,338.50**		**$3353.46**

*Recovery Period is based off of IRS Alternative Depreciation System
†Number of crops is based on the assumption of harvesting a crop every 8 months, having 1.5 harvests year^{-1}

Table 8. Establishment Crop Financial Summary

Category		$ Acre^{-1}	$ Hectare^{-1}	Total $
Operating Expenses	**†Labor**	$285.00	$704.95	$1,995.00
	†Labor Fringe	$54.30	$134.31	$380.10
	***Fuel**	$68.11	$168.46	$476.74
	***Fertilizer**	$122.63	$303.32	$858.40
	***Chemicals**	$186.02	$460.12	$1,302.14
	***Equipment Rental**	$768.60	$1,901.14	$5,380.22
	†Electricity	$171.43	$424.03	$1,200.00
	***Parts**	$87.94	$217.51	$615.55
	***Supplies**	$109.06	$269.76	$763.42
	†Miscellaneous	$70.96	$175.53	$496.74
Capital Expenses	**†Interest (9%)**	$64.72	$160.09	$453.05
	†Equipment	$408.33	$1,010.01	$2,858.33
	***Irrigation Pump & Pipe**	$33.33	$82.45	$233.33
	†Planting	$37.40	$92.51	$261.80
Other Expenses	**‡Harvesting**	$253.50	$627.03	$1,774.50
	‡Marketing & Business	$480.00	$1,187.28	$3,360.00
	‡Land (taxes)	$125.00	$309.19	$875.00
	‡Taxes and Insurance	$150.00	$371.02	$1,050.00
Total Expenses		$3,476.33	$8598.70	$24,334.32
Total Revenue	**$0.80 yard^{-2}**	$3,280.00	$8,113.07	$22,960.00
	$0.84 - $0.85 yard^{-2} (breakeven)	*$3,476.33*	*$8598.70*	*$24,334.32*
	‡$1.00 yard^{-2}	$4,100.00	$10,141.34	$28,700.00
Net Income	**$0.80 yard^{-2}**	**($196.33)**	**($485.63)**	**($1,374.32)**
	$0.84 - $0.85 yard^{-2} (breakeven)	***$0.00***	***$0.00***	***$0.00***
	‡$1.00 yard^{-2}	**$623.67**	**$1,542.64**	**$4,365.68**

Variable cost figures contained in Table 2 cover a period from June 2002 (planting) to June 2003 (harvest). Fixed costs are based upon the assumed 8 month growing season per crop.

* actual project expense
† some modifications made to actual project expense to fit scenario
‡ figures obtained from Lard, 2001

Table 9. Second Crop Financial Summary

Category		$ Acre^{-1}	$ Hectare^{-1}	Total $
Operating Expenses	**†Labor**	$245.00	$606.01	$1,715.00
	†Labor Fringe	$48.69	$120.44	$340.86
	***Fuel**	$46.76	$115.66	$327.31
	***Fertilizer**	$87.19	$215.65	$610.30
	***Chemicals**	$133.27	$329.64	$932.88
	***Equipment Rental**	$490.47	$1,213.17	$3,433.26
	†Electricity	$85.71	$212.01	$600.00
	***Parts**	$71.52	$176.90	$500.64
	***Supplies**	$27.78	$68.72	$194.47
	†Miscellaneous	$19.84	$49.08	$138.89
Capital Expenses	**†Interest (9%)**	$64.72	$160.09	$453.05
	†Equipment	$408.33	$1,010.01	$2,858.33
	***Irrigation Pump & Pipe**	$33.33	$82.45	$233.33
	†Planting	$37.40	$92.51	$261.80
Other Expenses	**‡Harvesting**	$253.50	$627.03	$1,774.50
	‡Marketing & Business	$480.00	$1,187.28	$3,360.00
	‡Land (taxes)	$125.00	$309.19	$875.00
	†*Taxes and Insurance	$150.00	$371.02	$1,050.00
Total Expenses		$2,808.52	$6,946.86	$19,659.62
Total Revenue	***$0.68 - $0.69 yard^{-2} (breakeven)***	*$2,808.52*	*$6,946.86*	*$19,659.62*
	$0.80 yard^{-2}	$3,280.00	$8113.07	$22,960.00
	‡$1.00 yard^{-2}	$4,100.00	$10,141.34	$28,700.00
Net Income	***$0.68 - $0.69 yard^{-2} (breakeven)***	***$0.00***	***$0.00***	***$0.00***
	$0.80 yard^{-2}	**$471.48**	**$1,166.21**	**$3,300.38**
	‡$1.00 yard^{-2}	**$1,291.48**	**$3,194.48**	**$9,040.38**

Variable cost figures contained in Table 2 cover a period from June 2003 to November 2003 (harvest). Fixed costs are based upon the assumed 8 month growing season per crop.

* actual project expense
† some modifications made to actual project expense to fit scenario
‡ figures obtained from Lard, 2001

Table 10. Economic Analysis Comparison for the Establishment Crop of Bermudagrass Sod Sold at \$1.00 yard^{-2}

	Cost acre^{-1}	Revenue acre^{-1}	Profit acre^{-1}
Adrian et al., 1995	\$2610.37/\$2782.04*	not available†	not available†
Cain et al., 2003	\$3535.00	\$735.00	(\$2800.00)
Lard, 2001	\$3302.80	\$4100.00	\$797.20
Martin and Wells, 2001	\$2391.00‡	\$3800.00	\$1409.00
dairy farm scenario	\$3476.33	\$4100.00	\$623.67

* early season/late season establishment
† The model used in this analysis was based on a seven year model and does not specify establishment crop return
‡ excludes land and irrigation well costs.
() indicates a loss

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