PHOSPHORUS AND NITROGEN LEACHING LOSSES DURING TURF ESTABLISHMENT

A Thesis

by

FRANCIS JOHN HAY

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

August 2003

Major Subject: Agronomy

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Approved as to style and content by:

Donald Vietor (Chair of Committee)	Clyde Munster (Member)
David Zuberer (Member)	Mark Hussey (Head of Department)

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ABSTRACT

Phosphorus and Nitrogen Leaching Losses During Turf
Establishment. (August 2003)

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Chair of Advisory Committee: Dr. Don Vietor

Concerns over water quality have led to required removal of 50 % of dairy manure phosphorus (P) from the impaired Bosque River Watershed. Application of composted dairy manure (CDM) to sod and moving P off the watershed with sod has prompted a study using box lysimeters to determine NO_3^--N and P leaching from transplanted sod grown with CDM and inorganic fertilizer as well as sprigs top-dressed with CDM. Treatments were applied to lysimeters filled with a silica sand medium. Three leaching events were imposed, leaching 0.07 to 0.09 % of the total P applied and 0.09 to 1.43 % of total N applied. Concentrations of P in leachate averaged 0.04 to 0.25 mg L^{-1}. Top-dressed CDM on sprigs leached statistically greater amounts of NO_3^--N than both transplanted sod treatments and greater P than the fertilizer grown sod. After the third leaching event, all treatments received an additional application of P, 100 kg ha^{-1} as CDM for manure-grown sod and sprigs, 50 kg ha^{-1} as triple superphosphate for fertilizer-grown sod. An additional three leachings were imposed. Top-dressed sprigs and transplanted sod leached similar amounts of P following the additional P application. Applied nutrients appeared to stay mainly in the sod layer and in the sand medium just below the sod layer. Top-dressed CDM appears to exhibit greater leaching losses of

NO_3^--N than transplanted manure-grown sod and greater N and P losses than transplanted fertilizer grown sod.

ACKNOWLEDGMENTS

I would like to thank my wife for all of her help and support through this process. She has stood beside me and given me the encouragement I needed to succeed; I love you Brooke. Support from my parents has made the journey this far easier and more fun, and for that love I thank them.

I would also like to thank my committee members, Dr. Clyde Munster and Dr. David Zuberer for their help and advice throughout the project and for just being available to answer questions. I put out a great thank you to my committee chair Dr. Don Vietor who convinced me that Texas A&M and research studies of composted dairy manure export through turf were timely places and opportunities for me. Dr. Vietor has put in much time and effort in answering questions and revising my writing. Because of Dr. Vietor, I believe I am a better scientist, critical thinker, and writer than when I arrived in College Station.

Thank you to all who have helped me along the way.

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INTRODUCTION

The Texas Commission on Environmental Quality (TCEQ) has identified impaired segments of the Upper North Bosque River in Erath and Comanche counties in north Texas according to the Texas Clean Water Act (CWA) section 303(d). A water body is listed if it exceeds a narrative standard for water quality. The current standard states that controllable sources of nutrients will not cause excessive growth of aquatic vegetation (30 TAC, Chapter 307.4 (e)). For each impaired water body the state must develop a total maximum daily load (TMDL) for each pollutant identified as contributing to the impairment. Nutrients, predominantly phosphorus (P), were determined to be the source of impairment in these watersheds that could be the cause of decreased water quality in and down stream of the watershed.

Concerns about water quality are inherent in conflicts between urban and agricultural sectors on Texas watersheds. The development of TMDL's for P under guidelines of the Texas CWA section 303(d) have accentuated disagreements between these two sectors on the Upper North and North Bosque watersheds. Storm-water runoff from dairy-waste-application fields has been identified as the predominant source of nonpoint source nutrients affecting the surface-water quality in the Upper North Bosque Watershed (McFarland and Hauck, 1999). A 50% reduction in soluble reactive P loads for the entire North Bosque watershed is being implemented to meet the current TMDL.

This thesis follows the style of Journal of Environmental Quality.

Point source addition of nutrients, such as municipal waste-water treatment plants and controllable nonpoint source nutrient additions are subject to the reduction of nutrient loading mandated in the P TMDL.

In order to achieve the goals of the TMDL for P, the TCEQ approved an implementation plan on 13 December 2002. The plan calls for removal of approximately 50% of the dairy-generated manure from the North Bosque River Watershed for use or disposal outside the watershed. In addition, the implementation plan will facilitate establishment of commercial composting facilities in the region and a sustainable market for the compost. The plan intends to move P off the watershed with the composted dairy manure (CDM).

At present, composting facilities are established but the market is uncertain for CDM. One potential market for composted dairy manure is developing in the turfgrass industry. The CDM can be applied during turfgrass sod production near manure sources and transported off the watershed in harvests of high-value sod crops. This system could use the product of manure composting facilities to move manure nutrients off the watershed and pay trucking costs through the turfgrass sod enterprise. The residues of manure nutrients are transplanted in sod to landscapes outside the impaired watershed. Because P moves slowly in soil, 46-77% of P applied as CDM can be removed with each sod harvest (Vietor et al., 2002). Nutrient loading on the impaired watershed, e.g., the Upper North and North Bosque, is reduced through sod exports.

Conversely, import of sod produced with CDM will increase nutrient loading on sites where sod is transplanted. The sod layer consists of a dense population of plants and tillers, manure residue, and a thin layer of soil removed during sod harvest. The extent of nutrient loading of surface waters from transplanted sod is dependent on the amounts of nutrients imported, slope, and other soil and climatic variables.

To export the amount of manure needed to meet the TMDL for P, sod producers will need to apply manure rates up to 200 kg P ha^{-1} on sod fields. These high manure application rates lead to harvest, export and transplanting of large amounts of manure P with sod. The sod may be transplanted onto diverse landscapes. A situation could exist in which the sod is placed over a site with sandy or organic soils, soils with preferential flow channels, and constructed or natural subsurface drainage. Nutrients leaving the sod layer could be transported through the subsurface drainage to surface waters (He et al., 1999, Sims et al., 1998). Knowledge of the nutrient balance in the sod layer will provide understanding of loads and fate of nutrients within and below the sod layer.

LITERATURE REVIEW

Background

Phosphorus Leaching

Most soils in the United States have sufficient P-adsorption capacity (Fe and Al oxides) to prevent significant leaching of P (Elliott et al., 2002). Yet, surface and ground water are hydrologically linked making it possible for leached P to enter surface water via subsurface flow (He et al., 1999). Applications of high rates of manure P on sandy or organic soils, or soils with subsurface drainage can increase the probability of P loss through subsurface flow (Sims et al., 1998). Although P leaching may not be a problem where P must move through great depths of soil before reaching groundwater, it is a concern where subsurface drainage or sandy soils provide pathways for rapid P movement. For example, transplanting of sod grown with high rates of CDM could contribute to large P losses on urban landscapes where subsurface drains and sandy soils are the underlying rooting material for the sod. Amounts of P leaching out of the sod layer need to be quantified in order to evaluate the possible pollution risk.

At high rates, P applied at the surface can leach below the surface layers and enter subsoil. Yet, P movement below the soil surface is dependant on soil type. Each soil type has a unique mix of sand, silt, and clay particles with associated cations that adsorb P. A surface application of P can be retained near the soil surface if P concentrations do not exceed sorption capacity. For example, P accumulated in the surface layers of a Lucedale fine sandy loam 3 years after surface application of fresh manure in the southern U.S. In contrast, P moved 15 cm deeper in Dothan loamy sand at the same location (Lund and Doss, 1980). The sandy Dothan soil allowed deeper penetration of P than the loamy Lucedale soil.

Placing treatments over a layer of sand with low P sorption capacity allows dissolved P to stay in the solution phase of soil. The sand particles, which adsorb very little of the P in leachate (Elliott et al., 2002, Chardon et al., 1997), can provide a medium on which transplanted sod can grow. Placing treatments on sand optimizes P recovery in leachate. Monitoring of the nutrients in leachate recovered from the sand medium provides a measure of loss from the sod layer.

At each transplanting site, the sod layer supplies more than one form of P that can be transported to soils below the surface. In addition, soil sorption capacity differs between organic and inorganic P forms. The concentration of extractable inorganic P for manured fields increased compared to an unfertilized control at depths to 210 cm in a calcareous soil (James et al., 1996). In contrast, total P containing both inorganic and organic forms exceeded the control concentration to a depth of only 30 cm at the same location. The contrasting leaching depths of organic and inorganic P indicate that the inorganic form of P may enter a drainage system while organic forms stay near the surface. An opposing conclusion was found when a field treated with manure for >50 years showed deeper P movement than fields treated with inorganic fertilizer for the same amount of time, suggesting organic P may have greater mobility (Eghball et al., 1996).

Given differences in leaching, each P form needs to be quantified to evaluate losses from the surface layer to subsurface drainage. The fractions of P in leachate from tile drains under silt loam and silty clay loam include dissolved reactive P (DRP) at (66-86%), total particulate P (TPP) (8-35%) and dissolved organic P (DOP) (4.5%) for soils amended with inorganic P (Heckrath et al., 1995). Manure amendment of the same soil contributed to a larger DOP fraction in leachate (11%). Similarly, leachate P from a sandy soil in column lysimeters treated with cattle slurry had a much higher percentage of DOP (96%) than a control (20%) (Chardon et al., 1997). Chardon et al. (1997) concluded that only a small portion of P in the slurry was highly mobile and that portion was mainly DOP. Quantifying phosphorus forms at different soil depths can illustrate which forms will be transported to groundwater and subsurface drainage.

Soil Tests

Understanding the form and quantity of N and P in sand medium, soil, CDM, and fertilizer applications, will help explain the form and concentration of leachate through such materials. Soil extraction and testing can be used to quantify nitrogen (N) and P in the surface layers. Sampling at the surface can help determine the forms of soil P with and without manure application. In southwest Oklahoma and the Texas panhandle, samples were taken from fields treated with animal manures and untreated controls to determine the predominant P forms (Robinson et al. 1995). The dominant form of P changed from organic in untreated soils to inorganic in treated soils. This agrees with the findings of Elliot et al. (2002) and Sharpley and Moyer, (2000) who found that inorganic P was the dominant form in biosolids and dairy compost. The form of P applied influences depth of P movement.

Soil sampling below the surface can determine which P forms move downward through soil. Total P (TP) in soil solution can decrease with increasing soil depth. In contrast DOP as a % of TP can increase with increasing soil depth after application of a slurry of cattle manure (Chardon et al., 1997). The concentration of each P fraction in soil will affect the depths of P leaching in a given soil and the portion of P that may be available to algae in surface waters.

Soil chemical and physical characteristics determine sorption and desorption kinetics, which strongly influence P movement through soil and loss to surface waters (Schoumans and Groenendijk, 2000). Extraction and analysis of soil P is a simple and fast way to quantify P fractions in soils with differing sorption characteristics. A simple soil test using water as a P extractant has been proposed to estimate pollution risk (Sharpley and Moyer, 2000). Measurements of P forms and concentrations in leachate can, in turn, be related to soil extractable P in water and other solutions. The relationship of soil test P extracted with distilled water to leachate concentration of P has been used in an attempt to estimate pollution potential of manure and other P imports (Sharpley and Moyer, 2000). In addition to water, other soil extractants (Mehlich III, Bray-Kurtz P1, Olsen, Fe oxide paper) can be used as soil tests to relate soil characteristics to P concentration and losses in runoff and leachate (Pote et al., 1996).

In previous studies, the water-extractable P was better correlated to runoff and subsurface drainage concentrations of P than other standard soil tests. For example, leaching of P from CDM was most closely related to water extractable inorganic P concentration (Sharpley and Moyer, 2000). Similarly, the water extraction of soil is potentially useful for estimating the environmental impact of surface applied manure (Hooda et al., 2000, Pote et al., 1996, Sharpley and Moyer, 2000) and manure imported through sod.

Research Objectives

1. Quantify the fate of N and P applied as CDM on sprigged turf and imported sod grown with manure and fertilizer.
2. Compare nitrate nitrogen (NO_3^--N) and P leaching among imported sod grown with manure or fertilizer and CDM applied on sprigged turf.
3. Quantify the fate of N and P applied as fertilizer on imported sod or CDM on manure-grown sod and sprigged turf.
4. Relate concentrations of N and P in soil extracts to leaching losses of N and P.

MATERIALS AND METHODS

Procedures

Experimental Design and Sampling

Twelve box lysimeters (surface area = 2.232 m^2 and depth = 0.67 m) were filled with washed silica sand. The sand medium was very low in extractable nutrients with 3 mg L^{-1} nitrate-nitrogen (NO_3^-–N) and 2 mg L^{-1} Phosphorus (P). Sand was previously used as a rooting medium in lysimeters by Chardon et al. (1997) and Elliot et al. (2002). Figure 1, Appendix A shows a diagram of lysimeters. Figure 2, Appendix A shows the particle size distribution of the lysimeter sand. The lysimeters were located at the Texas A&M Agricultural Experiment Station in Burleson County. A rainout shelter of translucent fiberglass excluded rain, but transmitted light for each replication of 3 lysimeters. The lysimeters are constructed of 10-gauge carbon steel. A 0.15 mm polyethylene sheet was placed on each lysimeter floor to provide a barrier between the sand medium and metal.

Two sampling devices were placed in each lysimeter (Fig. 1, Appendix A). First, a slotted well pipe (length = 45 cm, diameter = 31.8 mm) was fitted with a sampling tube and placed horizontally at the lowest point of the lysimeter floor to collect water samples and remove excess irrigation water. Second, a 30.5 cm diameter PVC pipe cap fitted with a drain assembly and sampling tube was placed just off center in the lysimeter. The cap opening was 38 cm above the bottom of the lysimeter. The cap sampler collected water from the cylinder of sand above the cap. Water in both sampling devices was pumped through flexible hoses extending to the surface.

An irrigation system was suspended above each lysimeter. The irrigation source consisted of a surface reservoir of irrigation water pumped from a subsurface well. Mean nutrient concentrations of the irrigation water were 0.10 mg L^{-1} P and 0.19 mg L^{-1} NO_3^--N. The water was filtered through 103 μm screen and pumped through underground PVC pipe to the lysimeters. Water was metered onto each lysimeter through 4 square-pattern nozzles each delivering 5.3 L min^{-1} at 0.14 MPa (20 psi) (Spraying Systems Co., Wheaton, IL,). The irrigation rate was calibrated using a grid of cups to collect water delivered to the lysimeter surface area per unit time (13.9 L min^{-1}).

Treatments

Three treatments were randomly assigned to the lysimeters within each of four replications in a randomized complete block design. Tifway 419 bermudagrass (*Cynodon dactylon*) was planted in the lysimeters as sprigs or sod. Tifway 419 was selected for its high value as a sod crop. Treatment 1 (MS) was transplanted sod grown with 200 kg ha^{-1} of P as CDM. Treatment 2 (FS) was transplanted sod grown with 50 kg ha^{-1} inorganic fertilizer P (triple superphosphate, 0-46-0). Treatment 3 (SM) was sprigged bermudagrass top-dressed with 100 kg ha^{-1} of P as CDM one day after planting. All treatments were applied 17 June 2002. Evapotranspiration was measured by a weather station located at the Texas A&M University golf course in College Station, TX. One irrigation of 2.4 mm was applied daily to each plot to balance evapotranspiration at the surface. Three leaching events comprising "leaching set I" were imposed 1, 4, and 7 weeks after treatment application. Before each leaching, excess water was removed from the bottom of the lysimeters to allow measurement of leachate volumes and prevent dilution during sampling.

The MS and SM treatments received an additional application of CDM (100 kg P ha^{-1}), and inorganic fertilizer (50 kg P ha^{-1}) was applied to the FS treatment on 15 August 2002. “Leaching set II” comprised three additional leachings, which were imposed 1, 4, and 7 weeks after the P application.

Nitrogen fertilizer was supplied after the first and second leaching event of set I and again after the first leaching event of set II at a rate of 25 kg ha^{-1} (2.5 g m^{-2}) of N as ammonium nitrate (33-0-0). All N and P applications and rates are given in Table 1, Appendix B.

The rates and forms of P imported or applied in treatments are currently used or proposed for turfgrass establishment. The fertilizer treatment 50 kg ha^{-1} of P is similar to traditional methods for turf sod production and transplanting which rely on inorganic fertilizer. The manure-grown sod treatment is a proposed method for growing, exporting and importing turf sod with high rates of CDM. The rate of 200 kg P ha^{-1} is applied as CDM during sod production to achieve high rates of P export through sod harvest. The P export through sod will reduce P loading and satisfy the TMDL for P in the North Bosque River Watershed.

Top-dressing with CDM is another proposed pathway for exporting P from impaired watersheds to turf on urban landscapes and establishing sod production fields on other watersheds.

Before leaching set II, 100 kg P ha^{-1} applied as CDM on MS and SM treatments and 50 kg ha^{-1} P as inorganic P on the FS treatment were consistent with potential homeowner applications of CDM or fertilizer for bermudagrass maintenance. The purpose was to determine if top-dressed applications of different nutrient sources would affect leaching losses.

Sampling and Analysis of Leachate

Water was sampled through flexible hoses connecting sampling devices to a vacuum pump and water trap. A 3 cm depth of irrigation water was applied and sampled for N and P analysis in the afternoon (CDT) for each leaching event. Leachate was collected 15 hours later. Total leachate volume was measured and sampled for N and P analysis. After the third leaching of the set I the leaching schedule was repeated following the application of CDM and P fertilizer for set II. Leachate and irrigation water samples were refrigerated in polyethylene bottles at 4° C for no longer than 4 weeks before filtering and 1 week after filtering through a 0.45 μm membrane filter. Samples for DOC analysis were frozen for 8 weeks after filtering. Water extracts of soil can be stored unfiltered at 4° C in polyethylene containers for up to 8 weeks without change in total dissolved P analysis (Ron Vaz et al., 1994). Conversely, molybdate reactive P (MRP) will increase with storage times as low as 1 to 2 days.

Filtered leachate and irrigation water samples were subsampled for separate analysis. One subsample was sent to the Texas A&M University Soil, Water, and Forage Testing Lab for analysis of total dissolved P through inductively coupled plasma optical emission spectroscopy (ICP) (Spectro Analytical Laboratories, Kleve, Germany) and

NO_3^--N through cadmium reduction using a Lachat Instruments Quick Chem 8000 (Lachat Instruments, Milwaukee, Wisconsin) (Keeney and Nelson, 1982). The second subsample was analyzed for molybdate reactive phosphorus (MRP) through the colorimetric malachite green method (Itaya and Ui, 1966) on a microplate reader (Dynex Technologies, Chantilly, Virginia) (D'Angelo et al., 2001). Soluble organic carbon was quantified in a third subsample on an OI 1010 UV catalyzed persulfate oxidation analyzer (OI Analytical, College Station). Total dissolved P (ICP), inorganic P (MRP), and % inorganic P ((MRP/ICP) x 100) was quantified for each leachate sample. Concentration of irrigation water was subtracted from leachate concentrations for each leaching event and that adjusted value was combined with leachate volumes to calculate the amount of N, P, and DOC lost from the sod layer on a per m^2 basis. Losses quantified for each sampler were expressed in the same units of mg m^{-2}.

Sampling and Analysis of Sand Medium and Soil

Plugs were removed from sod before transplanting and soil and plant components were separated. In addition, sprigs and the sand medium were sampled before treatments were imposed. The surface layer and sand medium were sampled after the third leaching event in leaching set I at depths of 0 to 150-mm, 150 to 300-mm, 300 to 500-mm, and 500 to 670-mm. In addition, the surface layer and sand medium were sampled at depths 0 to 50-mm, 50 to 150-mm, 150 to 300-mm, 300 to 500-mm, and 500 to 670-mm after the third leaching event of leaching set II. Eight soil cores were randomly sampled throughout each lysimeter to form a composite sample. Samples of the surface layer and sand medium were dried at 60° C and ground to pass a 2-mm sieve.

Physical and chemical properties of the sand medium and soil separated from transplanted sod plugs were measured to evaluate soil water movement from the sod layer into sand. As described previously, a textural analysis indicated > 98% of the sand medium comprised particle sizes > 50 µm. The coarse sand was used as a rooting medium in lysimeters to limit P sorption and desorption. In order to determine the sorption maximum of sand, P concentrations were measured after a sample of sand was shaken in solution containing a range of P concentrations (Nair et al. 1984). Final concentrations of the MRP were measured immediately using the malachite green method (Itaya and Ui, 1966). The P sorption maximum was calculated using the linear form of the Langmuir equation (Olsen and Watanabe, 1957). The P sorption maximum of the lysimeter sand was 6.9 mg P kg^{-1}, which is low compared to most agricultural soils. Soil separated from manure-grown sod had a soil texture with 88 % of soil particles > 50 µm. Similarly soil separated from fertilizer-grown sod had a soil texture with 94 % of soil particles > 50 µm. Sorption maximum for soil separated from manure-grown sod was -11.9 mg P kg^{-1} and was -3.7 mg P kg^{-1} for soil separated from fertilizer-grown sod. Both soils transplanted with sod exhibited a net desorption of P, showing a potential for leaching of P out of the sod layer.

The applications of treatments on top of sand with low sorption capacity are similar to the study by Elliott et al. (2002). Using sand with low P concentration and low P sorption makes it easier to detect differences in P leaching from the surface layer of treatments.

Samples of the sand medium and soil were analyzed for total N and P after Kjeldahl digestion (Parkinson and Allen, 1975) using ICP. In addition, the ICP was used to quantify P after extraction in acidified ammonium acetate - ethylenediamine tetraacetic acid (AAA-EDTA) (Hons et al., 1990). The NO_3^--N was determined through cadmium reduction after extraction with 1 N KCl (Keeney and Nelson, 1982). Both total and extractable N and P analyses were completed in the Texas A&M University Soil, Water, and Forage Testing Lab.

In addition to the AAA-EDTA extractant, samples of soil separated from plugs, and soil plus sand medium sampled after sets I and II were extracted in water. A 1 g soil sample was shaken in 25 mL of distilled water for 1 hour and immediately filtered through a 0.45 μm membrane filter. The MRP in filtered water extracts was analyzed within 24 hours. The ICP was used to measure total P within 3 days of the extraction with water.

Sampling and Analysis of Plant and Composted Manure

A lawn mower was used to remove clippings from each lysimeter, once after the second leaching event in sets I and II. The clippings were dried, weighed, and ground. The clippings and sprig samples were digested through a modified Kjeldahl procedure (Parkinson and Allen, 1975). Total P in the digest was analyzed using ICP, and total N in digest was analyzed using cadmium reduction (Keeney and Nelson, 1982). Total N and P in clippings and dry weights were used to compute removal during mowing. The P and N concentration and amounts in sprigs represented an addition to the system.

Composted manure was analyzed to quantify N and P amounts added to sprigged plots in set I and II and transplanted sod in set II. Samples of CDM were weighed, dried, and weighed again to determine percent water. Dried samples were ground to pass a 2-mm sieve. The composted manure samples were extracted in AAA-EDTA (Hons et al., 1990) and analyzed to estimate plant-available nutrients. The CDM was extracted with water similar to the soil separated from plugs in order to compare water extractable P to losses of P in leachate. The modified Kjeldahl digestion procedure (Parkinson and Allen, 1975), ICP and cadmium reduction were performed to estimate total N and P added to lysimeters through CDM.

Statistical Analysis

All statistical analysis was done using SPSS 11.0 for Windows (SPSS Inc. Chicago, Illinois). For each leaching event, the treatments were compared using the general linear model (GLM). Treatment means were compared through Fisher's least significant test (LSD). Treatment differences for leaching sets were determined with GLM repeated measures, which is best described as a split plot in time analysis. Differences between depths for each treatment were also determined with GLM and LSD. The significance level for comparison among treatments and depths was $P \leq 0.05$.

Treatment differences were determined for leached NO_3^--N, TP and cumulative N and P. In addition, NO_3^--N, total N, extractable P, TP, water extractable P, and % inorganic P in the sand medium and soil of imported sod were compared among treatments at each depth sampled**.** Depth differences were also determined for each soil component. In addition to comparisons within each individual leaching event, data from the three leaching events were pooled within leaching set I and II for GLM analysis.

RESULTS

Leaching Set I

Nutrients in the Sod Layer

The sod layer was made up of turf plants, soil, and manure or fertilizer residues for the transplanted sod treatments. The nutrient concentration in the CDM applied to the sprigs was compared to that of soil separated from sod (Table 2, Appendix B). Nitrate-N concentration in CDM of the SM treatment was substantially higher than soil and residue of the FS and MS treatments. Similarly, AAA-EDTA extractable P of CDM on the SM treatment was more than ten times greater than the imported sod treatments. Yet unlike NO_3^--N, AAA-EDTA extractable P in the MS soil was four times greater than P in the FS soil. Similarly, variation of water-extractable P among treatments followed the same trends. The percentage of water-extractable P in inorganic form ranged from 79 to 100 %.

Leached Nitrate

Nitrogen was applied to plots as transplanted sod, CDM, and inorganic fertilizer (ammonium nitrate) (Table 1, Appendix B). Nitrate-N concentration in leachate indicated the leaching potential of NO_3^--N was high. The NO_3^--N concentration (mg m^{-2}) in leachate samples was significantly different (α=0.05) between treatments for each leaching event during leaching set I and when all events within the set were pooled (Table 3, Appendix B). The NO_3^--N loss in leachate of the SM treatment was 15 and 30 times greater than the MS and FS treatments, respectively. Over the course of the 3 leaching events in leaching set I, the amount of nitrate leached decreased for all treatments. This decrease occurred even when ammonium nitrate was applied at a rate of 2.5 g m^{-2} actual N after the first and second leaching events. No net leaching of NO_3^--N from the FS treatment occurred in leaching event 3.

Leached Phosphorus

Phosphorus was applied to the plots in transplanted sod, sprigs, and CDM at rates shown in Table 1, Appendix B. Leaching losses of total dissolved P were significantly different (α=0.05) for leaching event 3 in set I and when pooled over leaching events within the set (Table 4, Appendix B). The P leached from the surface layer of the SM treatment was significantly greater (α=0.05) than the FS treatment, but not different from the MS treatment. The portion of P that was MRP was 7 % of the total dissolved P in leachate.

Leached Dissolved Organic Carbon

The DOC recovered in leachate was significantly different (α=0.05) between treatments for leaching events 2 and 3 within leaching set I and when events were pooled within this set (Table 5, Appendix B). The SM treatment was significantly greater (α=0.05) than the FS and MS treatments for leaching event 2 and when events were pooled in set I. Conversely, the SM and MS treatments were not significantly different for leaching event 3 of set I. When the DOC concentration of the irrigation water was subtracted from leachate concentrations, negative amounts of DOC leaching occurred in all leaching events for the MS and FS treatments. The DOC concentration in leachate was not greater than the DOC concentration in irrigation water. Suggesting the sod layer absorbed DOC from the irrigation water.

Cumulative Leaching Losses

Cumulative NO_3^--N leaching was summed over leaching events 1, 2, and 3 of leaching set I (Fig. 3, Appendix A). Significantly more (α=0.05) NO_3^--N was leached from the surface layer of the SM treatment than the MS and FS treatments. Cumulative NO_3^--N leaching of the SM treatment during set I was 15 times greater than the MS and FS treatments.

Cumulative P leaching was summed over events 1, 2, and 3 of set I (Fig. 4, Appendix A). The SM treatment was significantly higher (α=0.05) than the FS treatment. The MS treatment was not different from either the SM or FS treatments. The cumulative P leached for the MS, FS, and SM treatments reached 5, 4, and 7 mg m^{-2} respectively over the course of leaching set I.

Nitrogen in Sand Medium

Total and NO_3^--N in samples of the sand medium and soil of imported sod were quantified (Table 6, Appendix B). Nitrogen movement below the sod layer was detected as higher concentrations of total N within each depth increment. The NO_3^--N concentration within the sand medium after leaching set I was between 1 and 2 mg kg^{-1} and not significantly different (α=0.05) among depths sampled at 0 to 150, 150 to 300, 300 to 500, and 500 to 670-mm. The KCl-extractable NO_3^--N concentration ranged from 1 to 2 mg kg^{-1} in soil and sand after leaching set I.

In contrast to NO_3^--N, total N concentration in the soil profile of MS and SM treatments was significantly different (α=0.05) between depths for both treatments.

Total N concentration in the 0 to 150-mm depth was significantly greater (α=0.05) than all other depths (Table 6, Appendix B).

Phosphorus in Sand Medium

Different forms of phosphorus are present in the soil and sand rooting medium. In order to relate concentration of different forms of P to movement of P through soil, two soil P extractants and a Kjeldahl digestion method were used. The Kjeldahl digestion estimated total P in the sand medium and soil. The AAA-EDTA extraction (Hons et al., 1990) estimated plant-available P. Extraction of the sand medium with water removed less P, but removed P forms similar to those in leachate. The samples of the sand medium or sand overlaid with sod were shaken in distilled water for 1 hour, filtered, and analyzed. The P removed is termed water-extractable P. In addition to total P, MRP in the water-extractable fraction of P was quantified. The ratio of MRP over total water-extractable P provided an estimate of percent inorganic P. The extraction and analyses of different P forms contributed to understanding of the sources of P contributing to leaching from the sod layer.

Total P concentrations were similar among depths and treatments, but P extracted in AAA-EDTA were significantly different between depths (α=0.05) for the MS and SM treatments (Table 7, Appendix B). The P concentration in the 0 to 150-mm depth, which included the manure residue, was significantly greater (α=0.05) than other depths. In addition, P concentration in the 150 to 300-mm depth of the MS treatment was significantly greater (α=0.05) than the 500 to 670-mm depth. Similarly, the 150 to 300-

mm depth was significantly greater (α=0.05) than the 300 to 500 and 500 to 670-mm depths for the SM treatment.

The interaction between depth and treatment for P in AAA-EDTA extract was significant (α=0.05). Concentrations of P in the AAA-EDTA extract were significantly different (α=0.05) between treatments at the 0 to 150, 150 to 300, and 500 to 670-mm depths, but ranking among treatments varied among depths. At 0 to 150-mm and 150-300-mm depths, the SM treatment was significantly greater (α=0.05) than the FS treatment (Table 7, Appendix B). At the 500 to 670-mm depth, P concentration in the sand medium of the SM treatment was significantly greater (α=0.05) than the MS treatment.

The concentrations of water-extractable P were significantly different (α=0.05) between depths for all treatments with the surface 150 mm generally containing the greater water-extractable P. For the MS and SM treatments the 0 to 150-mm depth was significantly different (α=0.05) from other depths (Table 8, Appendix B). For the FS treatment, the 0 to 150-mm depth was significantly different (α=0.05) from depths below 300 mm.

An interaction between depth and treatment for water-extractable P concentration was significant (α=0.05). Water-extractable P concentration differed significantly (α=0.05) among treatments at the 0 to 150 and 300 to 500-mm depths only. Within 0 to 150-mm, all treatments are significantly different (α=0.05). The application of 100 kg ha^{-1} P as CDM increased water-extractable P nearly 3 fold in the SM treatment as compared with the FS treatment. At 300 to 500-mm, the manure P applications similarly increased P concentration in the sand medium of SM compared to the FS treatment (α=0.05).

The percent of MRP in total P of the water extract was significantly greater (α=0.05) on the surface 150 mm than at the lower depths for the MS and SM treatments (Table 9, Appendix B).

Nitrogen and Phosphorus in Bermudagrass Clippings

Grass clippings were taken after the second leaching event in sets I and II. Total P concentrations in clippings were significantly different (α=0.05) between treatments for clippings taken during leaching set I (Table 10, Appendix B). Clippings from the SM treatment contained significantly lower (α=0.05) percent P than clippings from the MS and FS treatments. The clippings harvested during leaching set II did not have significantly different (α=0.05) P contents. The total amount of P removed from the lysimeters as clippings was not significantly different (α=0.05) among treatments for either clipping event.

Regression Analysis

The relationship between soil-test nutrients in the sod layer and leaching losses revealed statistically significant (α=0.05) correlations for leachate NO_3^--N concentration versus surface soil contents of Total N and NO_3^--N (Fig 5, Appendix A). Regression of leachate total P concentration versus total P, AAA-EDTA extractable P, and water-extractable P was not significant (α=0.05) and had R^2 values of 0.35, 0.34 and 0.37, respectively. Total N when plotted against leached NO_3^--N yielded a higher R^2 of 0.99, yet had large gaps between points reducing its extrapolative value. Similarly the regression between water extractable DOP and leachate concentration of DOC was statistically significant (α=0.05) with an R^2 value of 0.69 (Fig. 6, Appendix A).

Leaching Set II

Prior to leaching set II, 100 kg ha^{-1} P was applied as CDM to the MS and SM treatments and 50 kg ha^{-1} of fertilizer P was applied to the FS treatment (Table 1, Appendix B). The analyses of leachate data for set II was identical to the analysis for set I.

Leached Nitrate

Nitrate-N leaching was significantly different between treatments (α=0.05) when leaching events were pooled over leaching set II and when leaching event 2 of set II was analyzed separately (Table 11, Appendix B). In leaching set II, the SM treatment was significantly greater (α=0.05) than the MS and FS treatments. Mean NO_3^--N losses for the SM treatment during set II and leaching event 2 were two times greater than the MS treatment and more than 76 times greater than the FS treatment. In leaching event 2 of set II, the SM treatment was significantly greater (α=0.05) than the FS treatment. Cumulative NO_3^--N leaching over leaching events 1, 2, and 3 of set II did not differ among treatments (Fig 3, Appendix A).

Leached Phosphorus

Leaching loss of total dissolved P in set II, was not significantly different (α=0.05) among treatments for individual events or pooled across events. In addition, cumulative P leaching over the three leaching events of set II did not differ among treatments. The portion of total dissolved P which was MRP was 19 % during leaching set II.

Leached Dissolved Organic Carbon

Surface applications of CDM to the MS and SM treatments added carbon with N, P, and other mineral nutrients. In contrast, no C was applied with the inorganic P fertilizer on the FS treatment. The C additions with CDM contributed to significantly greater (α=0.05) leaching losses of DOC in leachate from the SM than from the FS treatments during leaching events 1 and 3 of set II (Table 12, Appendix B). When the three leaching events were pooled, leaching losses of DOC were significantly different among the MS, FS, and SM treatments. Losses were greatest for the SM and least for the FS treatment.

Nitrogen in Sand Medium

Applications of CDM to MS and SM treatments provided N not available to the FS treatment. The only form of N applied to the FS treatment was inorganic ammonium nitrate. Yet, NO_3^--N concentrations were significantly different (α=0.05) between depths for the FS treatment only for set II. The 0-50 mm depth of the FS treatment was significantly higher (α=0.05) than all other depths (Table 13, Appendix B). Interaction between depth and treatment was not significant (α=0.05).

Total N concentrations were significantly different (α=0.05) among depths for all treatments (Table 14, Appendix B). The 0 to 50-mm depth of all treatments was significantly greater (α=0.05) than other depths. In addition, total N concentration in the

50 to 150-mm depth of the FS and SM treatments was significantly higher (α=0.05) than depths below 300 mm.

Phosphorus in Sand Medium

Extractable P concentrations were significantly different (α=0.05) among depths for all treatments (Table 15, Appendix B). Concentrations of AAA-EDTA-extractable P in the 0 to 50-mm depth were significantly greater (α=0.05) than other depths. For the MS treatment, the 50 to 150-mm depth was significantly higher (α=0.05) than depths below 150 mm. Similarly, AAA-EDTA-extractable P in the 50 to 300-mm depths of the SM treatment was significantly greater than depths below 300 mm.

The depth by treatment interaction was significant for AAA-EDTA-extractable P (α=0.05). The extractable P concentrations were significantly different (α=0.05) among treatments for the 0 to 50 and 50 to 150-mm depths only. The MS and SM treatments was significantly higher than the FS treatment (α=0.05) when compared at the 0 to 50-mm depth, but not at other depths. The SM but not the MS treatment was greater than the FS treatment at the 50 to 150-mm depth (α=0.05).

Total P concentrations in the sand medium were similar below 50-mm for all treatments, but significantly less (α=0.05) than concentrations in the sand medium and soil of sod in the depth of 0 to 50-mm (Table 16, Appendix B). The 50 to 150, 150 to 300 and 300 to 500-mm depths were significantly different (α=0.05) for the MS treatment only. The 50 to 150 and 150 to 300-mm depth are significantly different

(α=0.05) in the FS treatment. Total P concentration in the 50 to 150-mm depth of the SM treatments was significantly higher (α=0.05) than depths below 300 mm.

Similar to other P forms, water-extractable P concentrations were significantly different (α=0.05) between depths for all treatments (Table 17, Appendix B). The 0 to 50-mm depth was significantly greater (α=0.05) than other depths for all treatments. Depths of the MS and SM treatments were significantly different (α=0.05) between the 50 to 150 and depths below 300 mm. The 50 to 150-mm depth was significantly greater (α=0.05) than the 500-670-mm depth for the FS treatment.

The percentage of water-extractable P that is inorganic reveals the comparative leaching tendencies between inorganic and organic P (Table 18, Appendix B). In all treatments the 0 to 50-mm depth was significantly higher (α=0.05) than other depths. The portion of total P that is at the lowermost depth is 34 % less than in the uppermost depth of the sand medium for all treatments. The 50 to 150-mm depth was significantly greater (α=0.05) than depths below 300-mm for the SM treatment

Regression Analysis

Similar to leaching set I, regression between leachate total P concentration versus total P, AAA-EDTA-extractable P, and water-extractable P were not good indicators of leaching losses, which is reflected in low R^2 values of 0.00, 0.00, and 0.01, respectively. The leachate concentration of NO_3^--N was statistically correlated (α=0.05) with Total N in the surface soil and sand medium, yet yielded a low R^2 value of 0.58 (Fig. 7, Appendix A). As a result of low P concentrations and large gaps in NO_3^- concentrations, soil tests for N and P in surface soil plus sand medium were not good indicators of leaching losses for top-dressed CDM applied to sprigs or transplanted sod grown with fertilizer or CDM.

DISCUSSION

Leaching Set I

Leachate Components

The total N and P rates applied to the MS treatment were greater than both the SM and FS treatments (Table 1, Appendix B). The original hypothesis was that N and P leaching from the MS treatment, which was grown with 200 kg P ha^{-1} would be greater than treatments on which applications of N and P were smaller. In contrast, the results indicated cumulative NO_3^--N and P leaching were greater for the SM treatment. The results point to the differences in leaching losses of N and P with rates and forms applied in each treatment. The MS treatment was grown with 200 kg ha^{-1} P as CDM and the FS treatment with 50 kg ha^{-1} P as inorganic fertilizer before sod was harvested and transplanted. A period of nearly 6 months between nutrient application and sod harvest allowed mineralization of N and P in CDM, leaching, and plant uptake of soluble nutrient forms from soil in the sod layer. The N and P forms transplanted in the sod layer could have been less soluble and less prone to leaching than forms in CDM applied to the SM treatment. The SM treatment received an application of 100 kg ha^{-1} as CDM at the time the sod was transplanted. Composted dairy manure was low in nutrient levels 0.65 % N and 0.34 % P, yet was applied at a high rate equal to 100 kg P ha^{-1}.

The amount of N applied to the SM treatment was nearly equal to that applied to the FS treatment and 1.5 times lower than the MS treatment. Yet, cumulative NO_3^--N leaching losses were 30 and 15 times greater for the SM treatment than the FS and MS treatments, respectively. The SM treatment was top-dressed with CDM, which contained larger NO_3^--N concentrations than CDM residues in the manure-grown sod or soil imported in the fertilized sod. Extraction with KCl yielded 380 mg NO_3^--N kg^{-1} for CDM, 4.25 mg NO_3^--N kg^{-1} for sod produced with fertilizer, and 6.25 mg NO_3^--N kg^{-1} for manure-grown sod. The NO_3^--N in CDM prior to application was the product of mineralization and nitrification processes during composting of dairy manure (Sharpley and Moyer, 2000). Daily irrigation and each leaching after treatments were imposed contributed to decreased NO_3^--N levels in the surface layer during leaching set I and reduced differences between the sprigged and sodded treatments. Decreased NO_3^--N leaching in consecutive leaching events could have been due to removal of nitrate during consecutive leaching events and increased nitrogen requirement of the establishing turf. The greater NO_3^--N leaching from the SM compared to sod treatments could be influenced by the lack of an established root system and less plant uptake of NO_3^--N in the sprigged treatment. The sprigs did not show significant growth for the first four weeks of the experiment, during which time two leaching events occurred. Transplanted sod was actively growing during this time removing NO_3^--N from the sod layer in order to grow a new root system. Once the sprigs began to grow, clippings were removed from all treatments and N concentrations of clippings were not different between treatments, suggesting that nitrogen was sufficiently available in all treatments. Composted dairy manure also contained P which could potentially be leached out of the sod layer.

The high amount of P applied as CDM on the SM treatment contributed to greater P leaching losses compared to the FS treatment during leaching event 3, leaching set I and cumulative leaching losses in leaching set I. The sprigs were top-dressed with 100 kg ha^{-1} of P as CDM while the fertilizer sod was transplanted with 48.9 kg P ha^{-1}. Cumulative leaching loss of P from the SM treatment was 11 mg m^{-2} more than the FS treatment. Similar to NO_3^--N, higher cumulative P leaching from the SM treatment could be due to application of material with higher AAA-EDTA-extractable P. The AAA-EDTA-extractable P concentration of CDM applied to SM treatment was 1996 mg P kg^{-1}. The AAA-EDTA-extractable P concentration was only 162 mg P kg^{-1} for the MS and treatment, and 40 mg P kg^{-1} for the FS treatment. Higher AAA-EDTA-extractable P concentration corresponded to higher leaching. The correlation between AAA-EDTA-extractable P, total P, and water-extractable P versus P leaching, all yielded a low coefficient of determination and consequently they were not good predictors of P leaching loss. Under field conditions, net leaching losses are controlled by a number of factors including source of nutrient, rates of application, soil type, and cropping system as well as other environmental and climatic factors (Sims et al., 1998).

Manure-grown sod had received 200 kg P ha^{-1} in CDM prior to transplanting, sprigs were top-dressed with CDM at 100 kg P ha^{-1}, and fertilizer-grown sod received 50 kg P ha^{-1} as inorganic fertilizer. At these rates, the total P concentration of leachate ranged from 0.04 to 0.25 mg L^{-1}, with 7 to 19 % as MRP. Total P leached from lysimeters ranged from 0.07 to 0.09 % of the total P applied. Similar rates were applied to columns as biosolids and chicken manure by Elliot et al. (2002) and cattle slurry by Chardon et al. (1997). Sharpley and Moyer, (2000), used an 85 % lower rate of total P as dairy manure compost. The percentages of P in inorganic and organic forms in leachates were quite similar between this study and the 96 % recovery in organic form reported by Chardon et al. (1997). The percentage of organic and inorganic P recovered in leachate for the three treatments in this study were different from the 80 to 90 % recovery as inorganic P reported by Elliot et al. (2002) and the 63 to 92 % recovery in inorganic P fractions observed by Sharpley and Moyer, (2000). Differences in forms of P in leachate could be due to inorganic P reacting with soil particles in the loamy soil mixed with cattle slurry used by Chardon et al. (1997). Column lysimeters treated with only inorganic fertilizer leached P with a similar organic P percentages as columns treated with cattle slurry. In the study by Elliot et al. (2002), the use of a sand medium similar to this study reduced the impact that soil adsorption of P can have on leachate P concentrations. The medium used in the lysimeter can affect the leaching results.

Reaction of P with solid and liquid phases of soil and sand media can reduce the amount of P leaching out of a surface layer containing organic and inorganic P sources. Sharpley and Moyer, (2000) used only a membrane filter under composted manure and observed considerably higher concentrations and percentages of applied P in leaching losses than the studies that used a soil or sand medium. Placement of manure or compost over a sand medium has been shown to yield P concentrations of 0.04 to 0.25 mg L^{-1} for the present study and 1.25 to 2.5 mg L^{-1} in the study by Chardon et al. (1997). A much higher concentration of P in leachate was observed by Sharpley and Moyer, (2000). Total P in leachate reached an average concentration of 42 mg L^{-1} from leached columns containing dairy manure composted with soybean straw. The percentage of total P leached from biosolids, cattle slurry and dairy compost were 0.9, 0.5, and 15 % of total P applied, respectively (Chardon et al., 1997, Elliot et al., 2002, and Sharpley and Moyer, 2000). Sorption of P by soil or sand medium traps and prevents it from leaching.

Sand and soil sorption is not the only mechanism which prevents P from being leached. Plants and soil microbes play an active role in reducing the amount of P available for leaching. The biosolids, cattle slurry, and compost used in leaching studies by Elliot et al. (2002), Chardon et al. (1997) and Sharpley and Moyer, (2000) had no plant material growing in their systems. Plant roots absorb P and it is assimilated into tissues. The P immobilized in plants is not available until the plant dies and decays. Without plant uptake, soluble P in the biosolids, cattle slurry, and compost was either leached or trapped in liquid or solid phases of the soil or sand medium in columns, and lysimeters. The bermudagrass planted as sod or sprigs in my experiment began actively taking up P soon after application for sod and up to four weeks later for sprigs and probably reduced the P available for leaching.

Another influence on leaching of P is nitrogen fertilizer application. During leaching set I, each lysimeter received two applications of 2500 mg N m^{-2} as ammonium nitrate. Nitrogen application could minimize the difference in P leaching between treatments. Inorganic N application stimulated P uptake and growth of corn (*Zea mays L.*) and reduced leaching in columns treated with cattle slurry (Chardon et al., 1997). Similarly Heckrath et al. (1995) observed that N application reduced soil P concentration, and P concentration in drainage waters. Nitrogen fertilizer applications promoted turf growth in the lysimeters of this study, which increased plant demand for P and removed potentially leachable P from the sod layer.

Plant uptake and assimilation of soil minerals and sorption of P by soil particles limited P leaching, but DOC remained in the soil solution and could be leached at much higher rates. Background concentrations of DOC in irrigation water were relatively large (15 to 30 mg L^{-1}), yet the same water was used to irrigate all plots with equal volumes of water. The concentration of DOC in the irrigation water was subtracted from leachate values. All treatments initially leached less DOC than was applied as irrigation water due to absorption of DOC by soil and sand medium (Table 4, Appendix B). The treatment differences indicated mineralization released soluble organic carbon during composting of dairy manure which was transported in leachate (Sharpley and Moyer, 2000). The DOC was transported through matrix flow through the sand medium to the sampling devices in the box lysimeters in association with N and P dissolved in solution. The concentration of DOC leachate was positively related to water-extractable DOP in soil separated from sod and CDM applied to sprigs (Fig. 6, Appendix A). Similarly, Ron Vaz et al. (1993) observed a positive relationship between DOC and DOP in solution of an iron humus soil. Higher concentrations of water-extractable DOP in the surface corresponded to higher concentrations of DOC in leachate of box lysimeters. The water-extractable DOP in CDM was 21.3 mg DOP kg^{-1}, 8.1 mg DOP kg^{-1} in soil separated for manure-grown sod and, 1.0 mg DOP kg^{-1} in soil separated for fertilizer-grown sod. This relationship could explain why DOC concentrations in the SM treatment were greater than those in the MS and FS treatments.

Retention in Sand Medium

A portion of the N and P leached from the surface layer of treatments was expected to remain in the solution and solid phases of the sand medium. Nitrate-N levels in the sand medium were not different and all were less than 2 mg kg^{-1}. The reason for low nitrate levels in the sand medium could be due to low water holding capacity and leaching of nitrate in matrix flow through the sand medium. Alternatively, the nitrates could have been taken up by plant roots and immobilized by soil microorganisms. Total N, which includes organic forms, is less plant available and soluble, but could be transported in matrix flow through the sand medium. Phosphorus is also transported in matrix flow but is less soluble than nitrate and has a higher affinity to soil particles and Al, Fe, and Ca whose reaction depends on pH of the sand medium.

The majority of the P applied remained near the surface of the sand medium in the box lysimeters. For all treatments in this study, 56 % of P was located in the upper 300 mm of the lysimeter. Similarly, 72 % of P applied as poultry litter (9 Mg ha^{-1}) accumulated in the upper 300 mm of a fine silty loam, and fine sandy loam in Oklahoma (Sharpley et al., 1993). In the case of transplanted sod and sprigged sod, no tillage occurred after application of sprigs or sod. The applied P remained within and just below the layer of transplanted sod. Enrichment of the soil or sand below the sod layer could saturate the P sorption capacity of the soil or sand (Guertal et al., 1991). Reduced sorption capacity increases the probability of P movement through the surface layer and into subsoil or subsurface drainage. The CDM applied to the SM treatment had the highest AAA-EDTA-extractable P concentration of (1996 mg kg^{-1}) among the three treatments. The high levels of P applied in CDM could have saturated P sorption capacity of the sand medium and increased P leaching below the P saturated layer.

Phosphorus leached below the sod layer usually becomes sorbed by mineral soils. For example, P leached to depths of only 750 mm after long-term (50 years) applications of inorganic fertilizer and 1 m after long-term manure applications on a sandy-loam soil in western Nebraska. The annual manure application rates were 27 Mg ha^{-1} of raw cattle manure or 80 kg P ha^{-1} as inorganic fertilizer during each of 50 years (Eghball et al., 1996). For poorly drained soils with a deep water table, leaching to the 1 m depth is of little consequence. Concern about leaching losses arises when P is applied to sandy soils, high organic matter soils, and soils with an artificial drainage system (Sims et al., 1998).

The form of P as well as the soil characteristics affects downward movement of P. The percentage of water-extractable P that was MRP decreased with increasing depth in the sand medium for all treatments. Since MRP is generally considered inorganic P (Itaya and Ui, 1966), then the percentage of P that was inorganic in the sand medium at the bottom of the lysimeter was greater than near the surface. Similarly Eghball et al. (1996) suggested the downward movement of P in soil of manured fields was due to greater mobility of organic than inorganic P. Greater mobility of organic P was also noted by Chardon et al. (1997).

Each nutrient form sampled in the sand medium, soil, and leachates in lysimeters has a unique relationship with the soil. Nitrate-N is water-soluble and leached in matrix flow at the soil surface. In addition, the NO_3^--N is used by plants and microbes or leached. In contrast, total N, AAA-EDTA-extractable P, total P, and water-extractable P remained primarily in the sod layer at the soil surface. The contrasting distributions of NO_3^--N, total N and P, and extractable P among soil depths occurred for different reasons. Extractable inorganic P is adsorbed by Al, Fe, and Ca in the soil and organic P exists in both soluble and insoluble forms. Much of the total N is also bound in organic compounds. A portion of total soil N and P can be extracted by AAA-EDTA and water, which indicates the equilibrium between soluble and insoluble forms. The high concentration of total N and P at the surface compared to subsoil shows that little of the N and P was readily soluble and transported from the sod layer.

Nutrients in Bermudagrass Clippings

Clippings from the SM treatment were lower in total P concentration than clippings from the MS and FS treatments. The sprigs were slower to establish than sodded treatments. This slower development could have led to reduced intake of P by sprigs causing clippings from sprigs to have lower concentration of P. The concentrations were not different during the second clipping in leaching set II showing that the sprigged treatment began to adsorb P at a high enough rate to minimize the difference between treatments.

Leaching Set II

Leachate Components

Leaching set II took place directly following leaching set I and following an application of more P to all treatments. The CDM applied to the MS and SM treatments added N, P and C to the system. The inorganic fertilizer applied to the FS treatments added only P to the system. The source of nutrients applied affected leaching of N, P, DOC, and nutrient concentrations left in the soil. Quantities of N in leachates showed how different sources of N affect the leachate concentrations.

The applications of N in addition to the P in CDM explains the larger leaching losses of NO_3^--N for MS and SM treatments than the FS treatment fertilized with inorganic P only prior to leaching set II. The SM treatment received an application of CDM with KCl extractable NO_3^--N concentrations of 380 and 376 mg kg^{-1} before the initial leaching event of each set I and II. One application of CDM with KCl extractable NO_3^--N concentrations of 376 mg kg^{-1} was top-dressed on the MS treatment at the start of set II, but no N was applied with the P fertilizers on the FS treatment. The two applications of CDM to the sprigged treatment provided the highest dose of NO_3^--N and yielded the highest leaching losses. For all treatments, NO_3^--N concentrations in the soil and sand medium were lower for leaching set II than leaching set I possibly due to plant uptake by mature turf stands in all lysimeters. Higher rates of total N were applied to the MS and SM treatments because of CDM application.

Composted dairy manure also contains soluble organic compounds which can leach below the sod layer. The fact that no extra source of carbon was added to the fertilizer treatment may explain the significantly higher DOC in leachates of MS and SM than in those of the FS treatment in leaching set II. The FS treatment relies on plants and microorganisms to produce the DOC recovered in leachate. The DOC compounds are produced and leach during active plant growth. The difference between the MS and SM treatments is associated with differences between imported sod of the MS treatment and sprigged conditions of the SM treatment. Both treatments received the same application of CDM before leaching set II. The difference could stem from the first leaching set where the MS treatment was transplanted with highly mineralized CDM. The transplanted soil containing mineralized CDM residues was lower in water extractable DOP with 8.1 mg DOP kg^{-1}, than CDM applied to sprigs, which was 21.3 mg DOP kg^{-1}. The SM treatment received two applications of CDM with the high water-extractable DOP concentrations. As stated above a positive correlation between water-extractable DOP and leachate concentration of DOC was seen in this study (Fig. 6 Appendix A). The higher water-extractable DOP concentrations in CDM applied to the SM treatment corresponds to higher DOC concentrations in leachate for both the first and second leaching set (Tables 4 and 10, Appendix B). Leachate samples from the MS treatment and SM treatment were orange in color and subsequently had more DOC in them than the clear to yellow samples of the FS treatment. Leachate components represented dissolved nutrients and carbon escaping the sod layer in water.

Retention in Sand Medium

Total N concentrations were highest in the depth to 50 mm for all treatments and highest for NO_3^--N to the same depth in the FS treatment. The CDM transplanted or applied in the upper 50 mm of the MS and SM treatments contributed to the N present. In addition, supplemental, N fertilizer (ammonium nitrate) was applied to all treatments and stimulated a dense layer of turf roots in the upper 50 mm of the sand medium. The turfgrass growing in the lysimeters took up N and partitioned it among plant tissues. The most dense root growth took place in the upper 50 mm of the sand medium in lysimeters. The total N analyzed through Kjeldahl digestion included N from roots ground with the sand and soil in samples. Application of organic sources and plant uptake of N explains why NO_3^--N and total N concentrations were highest in the surface layer (0 to 50-mm).

For all soil components measured, greater total N, P and extractable N and P in the 0 to 50-mm depth than in deeper layers illustrates stratification among depths sampled. Although surface samples were taken to 150 mm in leaching set I, N and P stratification similar to leaching set II likely occurred within the 0 to 50-mm depth and below in leaching set I.

CONCLUSIONS

Although manure-grown sod contains greater amounts of both N and P than sod grown with inorganic fertilizer, leaching losses of NO_3^--N and P out of the sod layer were not statistically different. Turf established from sprigs top-dressed with CDM had greater leaching losses of both NO_3^--N and P out of the sod layer than transplanted sod grown with either CDM or inorganic fertilizer. When turf is established using manure-grown sod the potential for leaching losses of NO_3^--N, P, and DOC is no greater than turf established from traditional fertilizer-grown sod. Alternatively, in areas where turf is established using sprigs top-dressed with CDM, the potential for leaching losses of NO_3^--N, P, and DOC are greater than in areas where turf is established using transplanted sod.

When turf established from sprigs is top-dressed with CDM, leaching losses of NO_3^--N from the sod layer are greater than leaching losses from the sod layer when turf established from sod is top-dressed with CDM or inorganic P fertilizer. Top-dressing of CDM on turf established from sprigs or sod does not increase the potential leaching losses of P over established turf top-dressed with inorganic fertilizer. Top-dress application of CDM onto an established bermudagrass turf can be used without increasing the potential for P leaching over that of applying inorganic P fertilizer.

Composted dairy manure from the Upper Bosque River Watershed can be used to produce sod or can be top-dressed to turf outside the watershed without increasing the potential for leaching losses of P over that of traditional turf establishment and fertilization.

Establishing turf over a sandy soil or a soil with subsurface drainage may increase the potential for leaching losses of NO_3^--N, P, and DOC. Yet, in this study, even using a sand medium with a low sorption capacity, N and P applied as transplanted sod or CDM tended to remain near the surface. With the high rates of P applied during establishment of turf with manure-grown sod, and the low downward mobility of P, turf will probably need no supplemental P fertility for many years.

Leaching of N and P out of the sod layer is limited by plant uptake and soil sorption of P. Most soils in the USA have sufficient P-adsorption capacity to limit significant leaching of P (Elliot et al., 2002). Manure-grown sod can be used to remove P from impaired watersheds (Vietor et al., 2002) and can serve as a low-maintenance-high fertility sod with no greater potential for leaching losses than traditionally produced sod.

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APPENDIX A

FIGURES

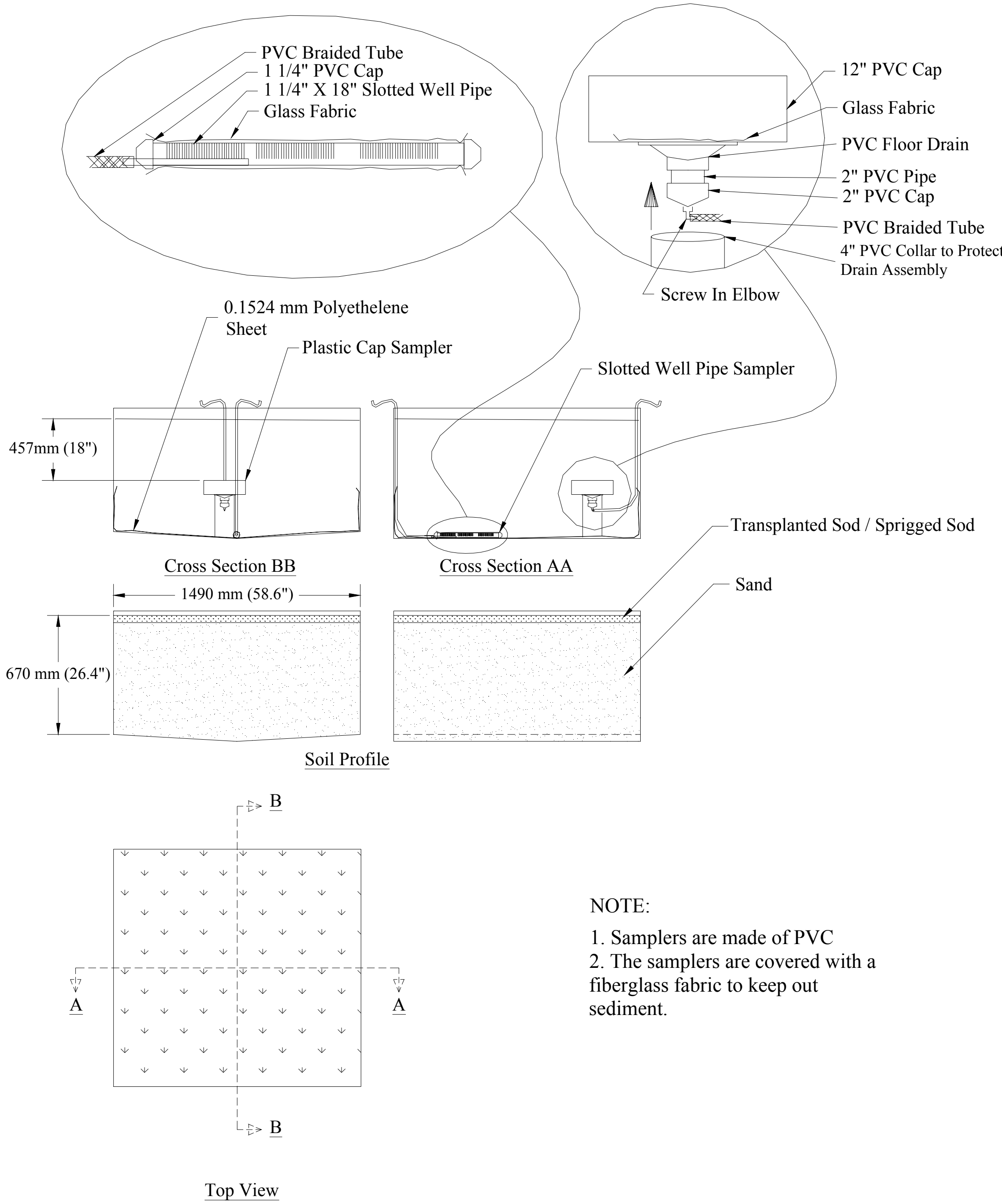

Fig. 1. Lysimeter sampler construction and placement. Lysimeters were constructed of 10 gauge carbon steel and placed in the ground to adjust to surrounding soil temperature. All sampler parts are made of PVC and can be purchased at any local plumbing supply or home improvement store.

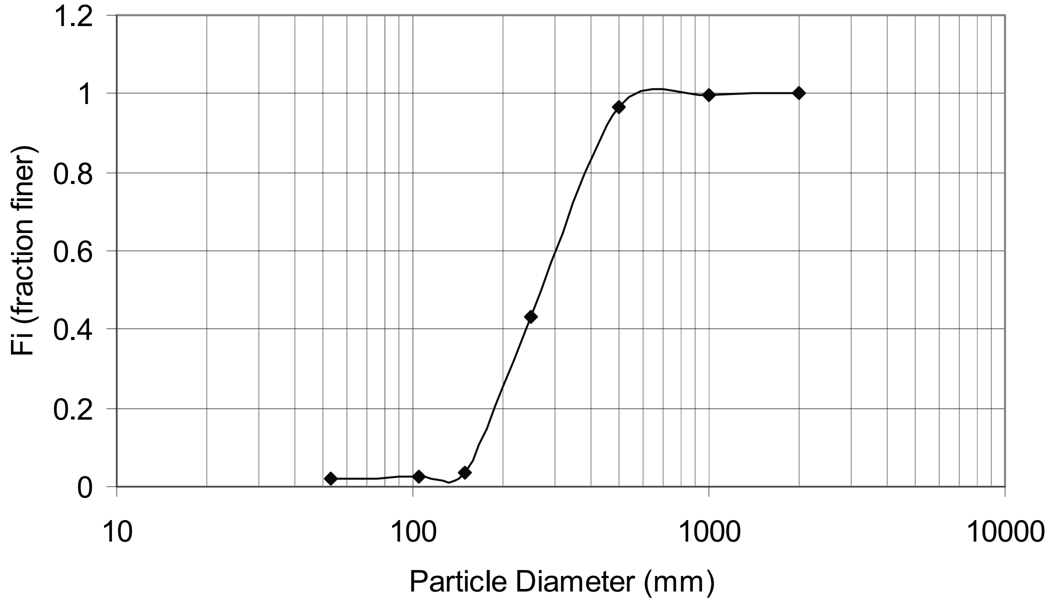

Fig. 2. Particle size distribution for sand medium. Fi (fraction finer) is the fraction of particles smaller than the corresponding X axis value. Example; Fi = 1.0 shows that 100% of the particles are finer than 1100-µm. The sand medium has 0.018% of particles finer than 50-µm. Sand fraction is all particles larger than 50-µm.

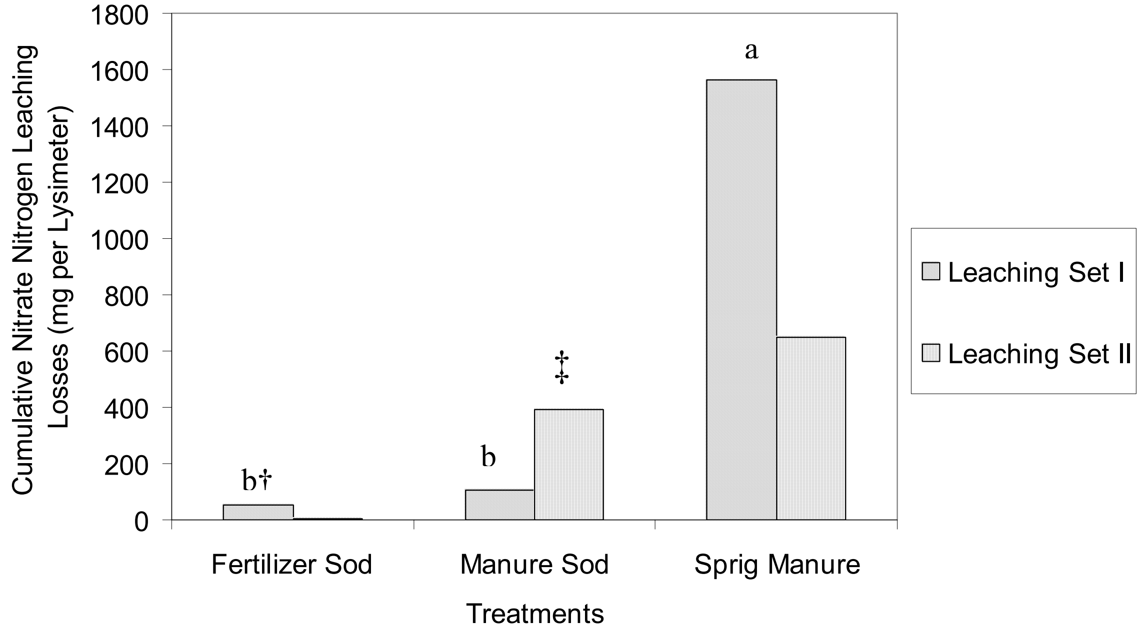

Fig. 3. Cumulative NO_3^--N leached from box lysimeters. Box lysimeters were 2.232 m^2. Leaching set I treatments include transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic P fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure). Leaching set II treatments include transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic P fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

† - treatments with the same lowercase letter within leaching set are not significantly different ($\alpha = 0.05$)

‡ - treatments were not significantly different in leaching set II

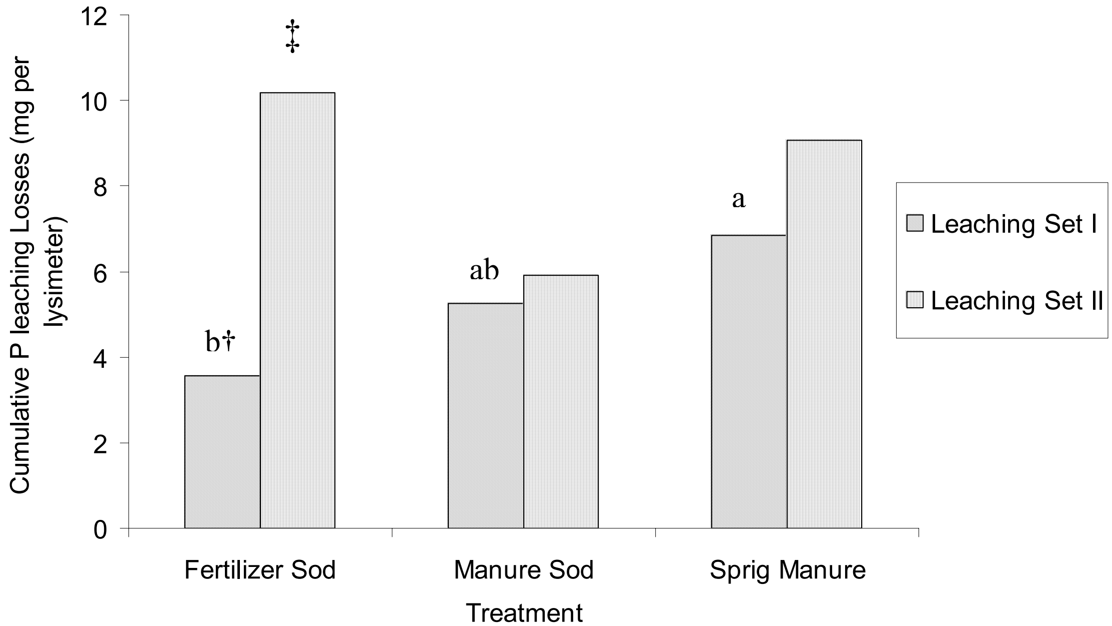

Fig. 4. Cumulative P leached from box lysimeters. Box lysimeters were 2.232 m^2. Leaching set I treatments include transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic P fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure). Leaching set II treatments include transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic P fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

† - treatments with the same lowercase letter within leaching set are not significantly different ($\alpha = 0.05$)

‡ - treatments were not significantly different in leaching set II

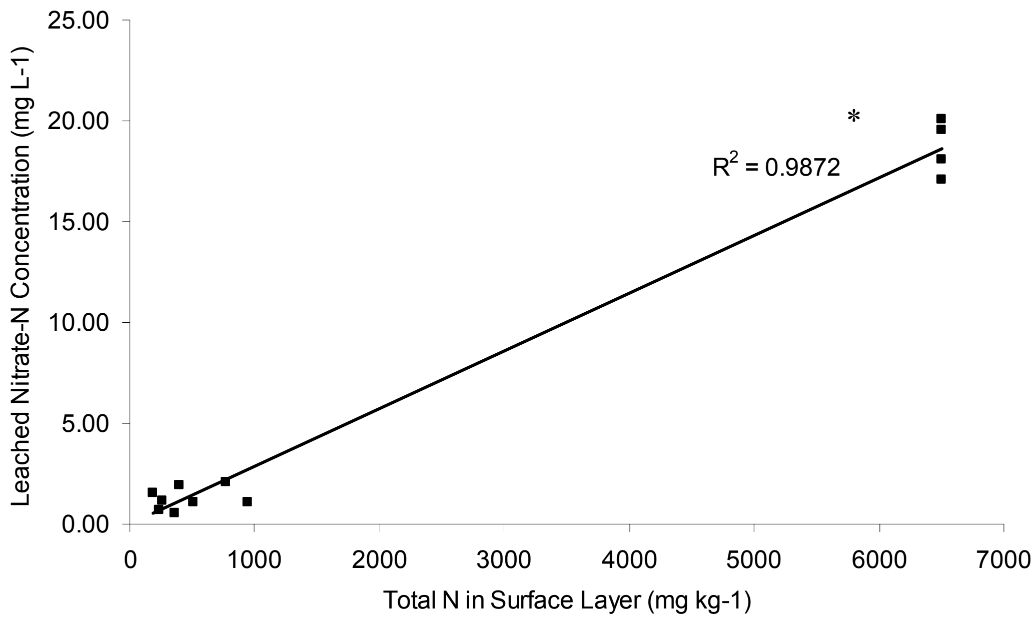

Fig. 5. Effect of total N in sod layer on NO_3^--N in leachate for leaching set I. Increase in total N concentration in surface layer corresponds with increase of NO_3^--N in leachate.

* - statistically significant at $\alpha = 0.05$

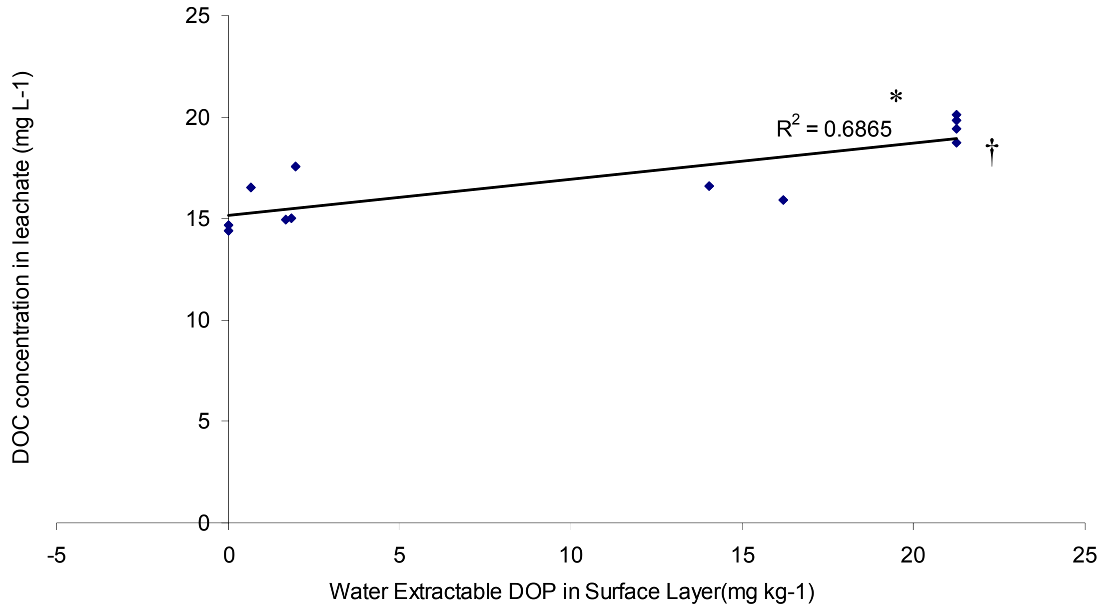

Fig. 6. Effect of water-extractable DOP in sod layer on DOC in leachate for leaching set I. Increase in water extractable DOP concentration in surface layer corresponds with increase of DOC in leachate.

* - statistically significant at $\alpha = 0.05$

† - irrigation water concentration of DOC was not subtracted from leachate concentration for this table, relationship was similar when irrigation values were subtracted

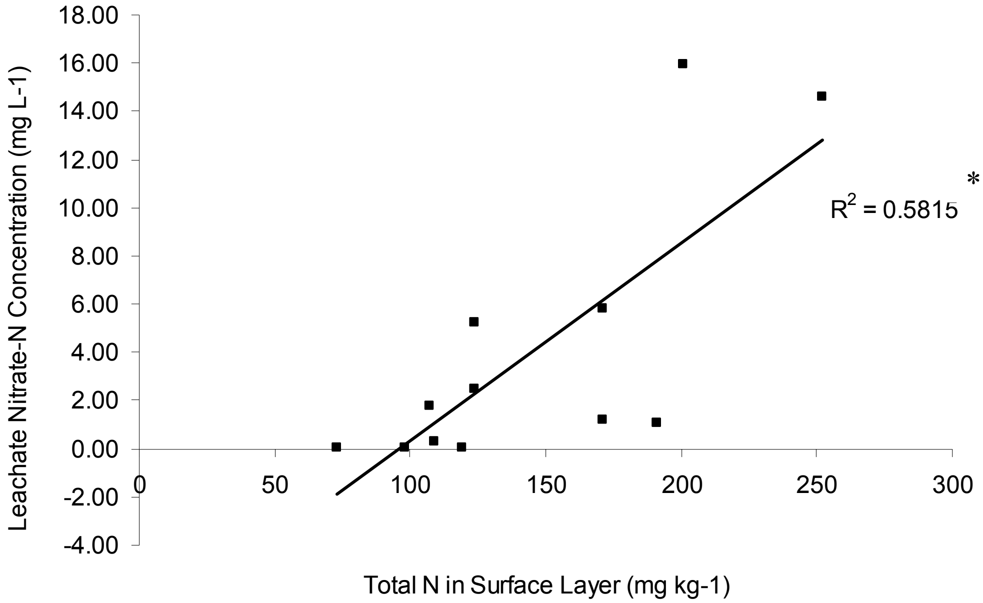

Fig. 7. Effect of total N in surface layer on NO_3^--N in leachate for leaching set II. Increase in Total N concentration in surface layer corresponds with increase of NO_3^--N in leachate.

* - statistically significant at $\alpha = 0.05$

APPENDIX B

TABLES

Table 1. Total nutrients applied to box lysimeters. Treatments consisted of sod grown with CDM (Manure Sod), sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure). Nitrogen and P were applied as sprigs or sod, and top-dressed CDM, in leaching set I. Leaching set II also received an application of CDM and inorganic fertilizer. Nutrient values are expressed in grams of nutrient applied per square meter.

Leaching Set I

	P Applied*				N Applied*			
Treatments	Sprigs or Sod ($g\ m^{-2}$)	Top-Dress CDM ($g\ m^{-2}$)	Inorganic Fertilizer ($g\ m^{-2}$)	Total ($g\ m^{-2}$)	Sprigs or Sod ($g\ m^{-2}$)	CDM ($g\ m^{-2}$)	Ammonium Nitrate ($g\ m^{-2}$)	Total ($g\ m^{-2}$)
Manure Sod	13.4	0	0	13.4	36.1	0	5.0	41.1
Fertilizer Sod	4.9	0	0	4.9	23.1	0	5.0	28.1
Sprig Manure	0.4	10.1	0	10.5	2.8	19.3	5.0	27.0

Leaching Set II

	P Applied*				N Applied*			
Treatments	Sprigs or Sod ($g\ m^{-2}$)	Top-Dress CDM ($g\ m^{-2}$)	Inorganic Fertilizer ($g\ m^{-2}$)	Total ($g\ m^{-2}$)	Sprigs or Sod ($g\ m^{-2}$)	CDM ($g\ m^{-2}$)	Ammonium Nitrate ($g\ m^{-2}$)	Total ($g\ m^{-2}$)
Manure Sod	13.4	8.2	0	21.6	36.1	13.6	2.5	52.2
Fertilizer Sod	4.9	0	5.0	9.9	23.1	0	2.5	25.6
Sprig Manure	0.4	18.3	0	18.7	2.8	32.9	2.5	38.2

* - all numbers are calculated from total digested nutrients

Table 2. Extractable N and P from materials applied as treatments. Soil separated from sod grown with CDM (Manure Sod), soil separated from sod grown with inorganic fertilizer (Fertilizer Sod), and CDM top-dressed on sprigs (Sprig Manure).

Leaching Set I

	P Concentrations			N Concentrations
	Soil Separated from Sod or CDM (mg kg^{-1})			Soil Separated from Sod or CDM (mg kg^{-1})
Treatments	AAA-EDTA-Extractable	Water-Extractable	Water-Extractable DOP	KCl-Extractable
Manure Sod	161.8	38.0	8.1	6.3
Fertilizer Sod	39.8	12.4	1.0	4.3
Sprig Manure	1996.0	120.8	21.3	380.0

Leaching Set II

	P Concentrations			N Concentrations
	CDM or Inorganic Fertilizer (mg kg^{-1})			CDM or Inorganic Fertilizer (mg kg^{-1})
Treatments	AAA-EDTA-Extractable	Water-Extractable	Water-Extractable DOP	KCl-Extractable
Manure Sod	1846	113.7	113.7	376.0
Fertilizer Sod	†	†	†	0.0
Sprig Manure	1846	113.7	113.7	376.0

† - Triple superphosphate (0-46-0) was applied to fertilizer sod treatment but did not receive analysis for extractable nutrients

Table 3. Leaching losses of NO_3^--N recovered from box lysimeters during 3 leaching events in leaching set I. Treatments consisted of transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure). Irrigation water contained a mean NO_3^--N concentration of 0.19 mg L^{-1}. Concentration of irrigation water was subtracted from leachate concentrations.

	Leach #1	Leach #2	Leach #3	Leaching Set I
	NO_3^--N (mg m^{-2})			
Manure Sod	45.0 (23.9)† b‡	51.5 (61.4) b	8.7 (16.1) b	35.1 (40.5) b
Fertilizer Sod	46.4 (39.8) b	5.2 (3.6) b	0.0 (0.1) b	17.2 (30.1) b
Sprig Manure	780.2 (684.8) a	702.8 (249.8) a	79.5 (37.3) a	520.8 (502.6) a
α Level	*	*	*	*

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - numbers in columns followed by the same lowercase letters are not significantly different (α = 0.05)

Table 4. Leaching losses of P recovered from box lysimeters during 3 leaching events in leaching set I. Treatments consisted of transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure). Irrigation water contained a mean total P concentration of 0.10 mg L^{-1}. Concentration of total P in irrigation water was subtracted from leachate concentrations.

	Leach #1	Leach #2	Leach #3	Leaching Set I
	Total P (mg m^{-2})			
Manure Sod	1.4 (0.3)†	2.4 (1.0)	1.5 (0.5) ab‡	1.7 (0.7) ab
Fertilizer Sod	1.3 (0.5)	1.4 (0.5)	0.9 (0.6) b	1.2 (0.5) b
Sprig Manure	1.9 (1.1)	2.4 (0.9)	2.5 (0.7) a	2.3 (0.9) a
α Level	NS	NS	*	*

* - statistically significant at $\alpha = 0.05$
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - numbers in columns followed by the same lowercase letters are not significantly different ($\alpha = 0.05$)

Table 5. Leaching losses of DOC recovered from box lysimeters during 3 leaching events in leaching set I. Treatments consisted of transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure). Irrigation water contained a mean DOC concentration of 24.5 mg L^{-1}. Concentration of irrigation water was subtracted from leachate concentrations.

	Leach #1	Leach #2	Leach #3	Leaching Set I
		Dissolved Organic Carbon (mg m^{-2})		
Manure Sod	-47.6† (39.4)‡	-31.3 (27.2) b§	-29.9 (25.0) ab	-36.7 (29.5) b
Fertilizer Sod	-50.7 (14.6)	-48.9 (23.6) c	-64.3 (25.6) b	-54.7 (21.0) b
Sprig Manure	-18.9 (29.7)	46.9 (15.9) a	22.3 (26.6) a	16.8 (36.1) a
α Level	NS	*	*	*

* - statistically significant at α = 0.05
NS - not significant
† - negative numbers signify that more DOC was added in irrigation water than was leached with leachate
‡ - numbers in parenthesis are standard deviation
§ - numbers in columns followed by the same lowercase letters are not significantly different (α = 0.05)

Table 6. Total N concentration in the sand medium, sampled after leaching set I. Sand from box lysimeters was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		Total Nitrogen (mg kg^{-1})		α Level
0 to 150	184.5 (53.0)† a‡ A§	99.8 (19.8) B	150.8 (43.1) a A	*
150 to 300	103.5 (32.8) b	82.0 (25.9)	109.5 (37.5) b	NS
300 to 500	95.8 (26.5) b	80.0 (28.0)	87.8 (37.7) b	NS
500 to 670	70.8 (41.5) b	85.3 (36.1)	87.0 (31.6) b	NS
α Level	*	NS	*	

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)
§ - treatments in rows followed by the same uppercase letters are not significantly different (α = 0.05)

Table 7. AAA-EDTA-extractable P in the sand medium, sampled after leaching set I. Sand from box lysimeters was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consist of transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		AAA-EDTA-Extractable Phosphorus (mg kg^{-1})		α Level
0 to 150	26.5 (19.8)† a‡ A§	3.5 (2.5) B	43.5 (8.7) a A	*
150 to 300	3.8 (1.0) b A	1.8 (0.5) B	17.0 (11.6) b A	*
300 to 500	3.5 (4.4) bc	1.5 (0.6)	5.8 (2.1) c	NS
500 to 670	1.8 (0.5) c B	3.0 (3.4) AB	7.3 (3.4) c A	*
α Level	*	NS	*	

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)
§ - treatments in rows followed by the same uppercase letters are not significantly different (α = 0.05)

Table 8. Water-extractable P in the sand medium sampled after leaching set I. The sand medium was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		Water-Extractable Phosphorus (mg kg^{-1})		α Level
0 to 150	8.2 (3.1)† a‡ B§	4.1 (0.7) a C	11.2 (1.5) a A	*
150 to 300	3.1 (1.1) b	3.4 (0.9) ab	4.3 (1.3) b	NS
300 to 500	3.2 (0.9) b AB	2.4 (0.6) b B	4.2 (0.7) b A	*
500 to 670	3.6 (1.2) b	2.5 (0.7) b	4.2 (0.8) b	NS
α Level	*	*	*	

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)
§ - treatments in rows followed by the same uppercase letters are not significantly different (α = 0.05)

Table 9. Percentage of MRP in water extracts of the sand medium, sampled after leaching set I. The percentage MRP is the ratio of MRP to total P. The sand medium was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		Percentage MRP (%)		α Level
0 to 150	84.3 (15.8)† a‡	72.3 (14.4)	87.5 (11.1) a	NS
150 to 300	71.0 (17.5) b	74.0 (12.9)	67.3 (8.8) b	NS
300 to 500	75.3 (20.7) b	78.3 (36.9)	71.5 (13.9) b	NS
500 to 670	72.5 (14.5) b	71.3 (21.1)	66.3 (18.9) b	NS
α Level	*	NS	*	

* - statistically significant at $\alpha = 0.05$
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different ($\alpha = 0.05$)

Table 10. Concentration of N and P in grass clippings. A lawnmower was used to remove clippings from bermudagrass growing in box lysimeters. Treatments consisted of transplanted sod grown with CDM (Manure Sod), transplanted sod grown with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM.

	Leaching Set I		Leaching Set II	
	Total N and P in Bermudagrass Clippings (%)			
	Total N	Total P	Total N	Total P
Manure Sod	2.3 (0.1)†	0.24 (0.02) a‡	2.4 (0.2)	0.3 (0.03)
Fertilizer Sod	2.5 (0.2)	0.23 (0.03) a	2.3 (0.2)	0.3 (0.05)
Sprig Manure	2.3 (0.1)	0.18 (0.01) b	2.5 (0.2)	0.2 (0.02)
α Level	NS	*	NS	NS

* - statistically significant at $\alpha = 0.05$
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - numbers in columns followed by the same lowercase letters are not significantly different ($\alpha = 0.05$)

Table 11. Leaching losses of NO_3^--N recovered from box lysimeters during 3 leaching events in leaching set II. Treatments consisted of transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure). Irrigation water contained a mean NO_3^--N concentration of 0.19 mg L^{-1}. Concentration of irrigation water was subtracted from leachate concentrations.

	Leach #1	Leach #2	Leach #3	Leaching Set II
	NO_3^- -N (mg m^{-2})			
Manure Sod	214.2 (255.9)†	153.6 (224.4) ab‡	25.9 (37.5)	131.2 (196.7) b
Fertilizer Sod	-0.9§ (0.2)	4.4 (3.9) b	0.04 (0.1)	1.17 (3.2) b
Sprig Manure	242.2 (180.9)	335.3 (262.4) a	70.7 (75.9)	216.1 (205.9) a
α Level	NS	*	NS	*

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)
§ - negative numbers signify that more DOC was added in irrigation water than was leached with leachate

Table 12. Leaching losses of DOC recovered from box lysimeters during 3 leaching events in leaching set II. Treatments consisted of transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top dressed with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure). Irrigation water contained a mean DOC concentration of 24.5 mg L^{-1}. Concentration of irrigation water was subtracted from leachate concentrations.

	Leach #1	Leach #2	Leach #	Leaching Set II
		Dissolved Organic Carbon (mg m^{-2})		
Manure Sod	-56.7† (50.6)‡ ab§	357.8 (87.3)	199.7 (45.8) ab	166.9 (187.6) b
Fertilizer Sod	-140.4 (47.7) b	67.2 (57.0)	-45.4 (42.7) b	-39.5 (99.3) c
Sprig Manure	35.9 (81.4) a	409.7 (89.9)	249.9 (26.3) a	231.8 (172.5) a
α Level	*	NS	*	*

* - statistically significant at α = 0.05
NS - not significant
† - negative numbers signify that more DOC was added in irrigation water than was leached with leachate
‡ - numbers in parenthesis are standard deviation
§ - numbers in columns followed by the same lowercase letters are not significantly different (α = 0.05)

Table 13. Concentrations of NO_3^--N in the sand medium of box lysimeters, sampled after leaching set II. The sand medium was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		NO_3^- -N (mg kg^{-1})		α Level
0 to 50	4.5 (1.9)†	2.8 (0.5) a‡	3.5 (1.0)	NS
50 to 150	2.0 (0.0)	2.0 (0.0) b	2.5 (0.6)	NS
150 to 300	2.0 (0.0)	2.3 (0.5) b	2.3 (0.5)	NS
300 to 500	2.0 (0.0)	2 .0 (0.0) b	2.3 (0.5)	NS
500 to 670	2.5 (0.6)	2 .0 (0.0) b	2.8 (0.5)	NS
α Level	NS	*	NS	

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)

Table 14. Total N concentration in the sand medium of box lysimeters, sampled after leaching set II. The sand medium was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		Total Nitrogen (mg kg^{-1})		α Level
0 to 50	367.5 (99.1)† a‡	285.0 (128.7) a	263.8 (112.3) a	NS
50 to 150	110.0 (14.7) b	129.8 (26.8) b	124.0 (28.1) b	NS
150 to 300	100.3 (16.7) b	107.0 (44.3) bc	98.0 (8.2) bc	NS
300 to 500	83.3 (6.1) b	83.8 (10.2) c	88.0 (21.6) c	NS
500 to 670	95.5 (17.1) b	83.8 (12.8) c	85.8 (5.2) c	NS
α Level	*	*	*	

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)

Table 15. AAA-EDTA-extractable P concentrations in the sand medium of box lysimeters, sampled after leaching set II. The sand medium was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		AAA-EDTA-Extractable Phosphorus (mg kg^{-1})		α Level
0 to 50	90.5 (34.1)† a‡ A§	26.5 (13.1) a B	112.8 (38.7) a A	*
50 to 150	13.0 (8.5) b AB	6.3 (1.7) b B	18.3 (5.4) b A	*
150 to 300	6.0 (3.8) c	5.5 (3.7) bc	12.0 (7.3) b	NS
300 to 500	2.8 (0.5) c	3.0 (1.2) cd	2.5 (1.3) d	NS
500 to 670	2.5 (0.6) c	2.0 (0.8) d	6.0 (3.4) c	NS
α Level	*	*	*	

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)
§ - treatments in rows followed by the same uppercase letters are not significantly different (α = 0.05)

Table 16. Total P concentration in the sand medium of box lysimeters, sampled after leaching set II. The sand medium was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		Total Phosphorus (mg kg^{-1})		α Level
0 to 50	110.8 (23.3)† a‡	49.9 (13.2) a	126.1 (44.8) a	NS
50 to 150	36.7 (7.0) b	29.5 (6.3) b	35.5 (10.6) b	NS
150 to 300	28.6 (4.3) c	24.1 (2.3) c	24.3 (5.3) b c	NS
300 to 500	22.9 (3.9) d	22.7 (2.3) c	23.9 (7.7) c	NS
500 to 670	26.2 (1.5) cd	21.6 (4.0) c	24.8 (3.4) bc	NS
α Level	*	*	*	

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)

Table 17. Concentrations of water-extractable P in the sand medium of box lysimeters, sampled after leaching set II. The sand medium was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)	Water Extractable Phosphorus (mg kg^{-1})			α Level
0 to 50	13.3 (6.1)† a‡	11.4 (4.7) a	14.9 (5.7) a	NS
50 to 150	5.3 (1.1) b	4.7 (1.1) b	6.1 (1.0) b	NS
150 to 300	4.7 (1.2) b	4.4 (0.6) bc	4.5 (1.0) bc	NS
300 to 500	4.3 (0.7) bc	3.6 (0.3) bc	3.9 (0.5) c	NS
500 to 670	3.6 (0.4) c	3.5 (1.3) c	4.0 (0.8) c	NS
α Level	*	*	*	

* - statistically significant at $\alpha = 0.05$
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different ($\alpha = 0.05$)

Table 18. The percentage MRP in water extracts of the sand medium of box lysimeters, sampled after leaching set II. Percent MRP is the ratio of MRP to total P. The sand medium was sampled at multiple depths. Eight cores were combined to make one composite sample per lysimeter. Treatments consisted of transplanted sod top-dressed with CDM (Manure Sod), transplanted sod top-dressed with inorganic fertilizer (Fertilizer Sod), and sprigs top-dressed with CDM (Sprig Manure).

	Manure Sod	Fertilizer Sod	Sprig Manure	
Depth (mm)		Percent MRP in Water Extractable-Phosphorus (%)		α Level
0 to 50	81.3 (9.4)† a‡	81.0 (10.0) a	82.5 (3.7) a	NS
50 to 150	64.5 (7.7) b	62.5 (8.7) b	64.8 (9.0) b	NS
150 to 300	60.3 (1.5) b	61.3 (15.2) b	57.5 (6.6) bc	NS
300 to 500	59.8 (7.3) b	58.3 (14.8) b	50.3 (8.7) c	NS
500 to 670	57.5 (7.6) b	54.0 (11.5) b	51.5 (10.2) c	NS
α Level	*	*	*	

* - statistically significant at α = 0.05
NS - not significant
† - numbers in parenthesis are standard deviation
‡ - depths in columns followed by the same lowercase letters are not significantly different (α = 0.05)

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Background:

I was born in Gothenburg Nebraska on April 3, 1979 to Paul and Julie Hay. Growing up in Beatrice NE, I attended Beatrice High School graduating in May of 1997. I was married on November 23, 2002 to Brooke Amanda Hubbard. Brooke earned a B.S. with honors in Civil Engineering from the University of Nebraska-Lincoln in 2000.

Education: Texas A&M University
M.S. Agronomy
Graduation Date: August 2003

University of Nebraska-Lincoln
B.S. Agronomy
Graduation Date: August 2001

Professional Experience:

Graduate Assistant: Texas A&M University
- Research dealing with transport of P through sod and fate of N and P during turf establishment
- Analyzing data using SPSS-11.0 and Microsoft Excel

Assistant Residence Director: University of Nebraska
- Supervision of international night security staff
- Duty scheduling for 12 member Resident Assistant staff.

Soybean Seed Production Intern: Mycogen Seeds
- Helped scout 10,000 acres of seed soybeans to insure purity and quality of soybean seed.