RESPONSE OF NITROGEN AND PHOSPHORUS LEACHING AND SOIL PROPERTIES TO APPLICATIONS OF BIOSOLIDS DURING TURFGRASS ESTABLISHMENT

A Thesis

by

JAMES PATRICK KERNS

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

December 2004

Major Subject: Agronomy

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December 2004
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ABSTRACT

Response of Nitrogen and Phosphorus Leaching and Soil Properties to Applications of Biosolids During Turfgrass Establishment. (December 2004)

James Patrick Kerns, B.S., North Carolina State University

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Regulations for total maximum daily loads require management of phosphorus loading from farms and municipalities. This study evaluated environmental impacts of a system for using and exporting the phosphorus in composted dairy manure (CDM) and composted municipal biosolids (CMB) through turfgrass sod. Responses of soil physical, chemical, and biological properties within and below the sod layer were monitored during turfgrass establishment in two experiments under greenhouse conditions. During turf establishment in column lysimeters, phosphorus and nitrogen leaching from an amended surface layer through soil were evaluated. In addition, growth of turf was related to the observed changes in soil nutrients and properties. In the first experiment, four replications of a factorial design comprised three soil types (USGA greens sand, Windthorst fine sandy loam [fine, mixed, thermic Udic Paleustalf], Houston black clay [fine, smectitic, thermic, Udic Hapustert]), two dairy manure rates (200 kg P ha^{-1}, 400kg P ha^{-1}), and two turf species (St. Augustinegrass (*Stenotaphrum secundatum* [Walt.] Kuntze var. Raleigh) and Tifway 419 Bermudagrass (*Cynodon dactylon* [L.] Pers. *x C. transvaaleensis* Burtt-Davy). Columns received three separate leaching events in which a 9-cm depth of distilled water was applied. A similar experimental design was implemented for Experiment 2 in January 2004. Treatments consisted of the same three soils and three volume-based rates of CDM and CMB (0, 150, 250 cm^3 L^{-1}) during establishment of St. Augustinegrass turf. Columns received one pore volume of distilled water on three separate occasions. In both experiments, soil physical properties (bulk density, water infiltration rate, and water content) and microbial populations were unaffected by CDM or CMB. Applications of CDM at P-based rates utilized in the first experiment yielded no variation of leaching loss among rates of P or N. Most of the P applied was retained in the top 10 cm of soil. When large volume-based rates were used, leaching losses of P and N varied among CDM or CMB application rates. Leaching losses were only observed in the USGA sand and were highest for the 250 cm^3 L^{-1} rate of CDM or CMB. Regardless of compost source, applications of organic amendments at volume-based rates can increase leaching loss of P and N on sandy soils. However, if P-based rates are used there is little risk for leaching loss of N and P during sod establishment.

DEDICATION

This thesis is dedicated to my father David Kerns and my late mother Evelyn Kerns (1949-2003). Without their love and support none of this would have been possible.

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I would like to thank my mom and dad for all the advice and financial aid through my journey at Texas A&M. I could not have done this without their help and support. For that I love them dearly. Likewise, support from my brothers and sisters helped me get through the tough times. Ginger, Kathy, David, Tom and Aaron I thank you for your love and support during my time spent here in Texas. I would like to thank my beautiful girlfriend for her love and support. Our daily chats always seemed to calm me down and prepare me for another day. I love you Anna. Finally, to my Aunt Donna and Uncle Kim, I owe a special thank you. They were always ready to help during times of need or just when I was down.

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INTRODUCTION

Segments of the Upper North Bosque River within Erath and Comanche counties in central Texas have been listed among impaired water bodies by the Texas Commission on Environmental Quality (TCEQ) (Title 30 Texas Administrative Code 1991). According to the Total Maximum Daily Load (TMDL) criterion of TCEQ, the Bosque River segments are impaired if nutrient sources cause significant growth of aquatic vegetation. Soluble reactive phosphorus (P) has been identified as the pollutant contributing to growth of aquatic vegetation and impairment of the Bosque River. Storm water runoff from dairy-waste application fields has been identified as a predominant source of soluble reactive P in the Bosque River (McFarland and Hauck, 1999). To implement the current TMDL for the Bosque segments, TCEQ specified soluble reactive P loads must be reduced 50%.

The TCEQ developed an implementation plan requiring removal of 50% of dairy manure from the North Bosque watershed. In addition, federal and state programs are subsidizing hauling of dairy manure to composting facilities and of composted manure to public-works projects on other watersheds. Composting facilities have been established, but market alternatives to the public works projects are uncertain. One option could be application, export and marketing of composted dairy manure (CDM) through turfgrass sod.

This thesis follows the style and format of Journal of Environmental Quality.

The high economic value of turfgrass sod could enable sod producers to cover the cost of hauling composted manure to production sites. Furthermore, surface application of composted manure and P retention in the sod layers allows removal of 46 to 77% of P with each sod harvest (Vietor et al., 2002).

In addition to removing CDM from the impaired watershed, application and export of CDM can enhance physical and biological properties of the soil transplanted with sod. Water infiltration rates, water holding capacity, and bulk density are among the physical properties altered by manure applications (Miller et al., 2002; Eghball, 2002). In addition, changes in nutrient concentrations, C/N ratios, microbial diversity and activity are pertinent to biological quality of soil and turfgrass.

The goal of manure export through sod is reduced nutrient loading on watersheds, but questions still exist about benefits and drawbacks of manure management in turfgrass sod systems. Potential benefits related to soil, turf quality, and water use provide incentives for manure use by turfgrass sod producers. Yet, manure properties and benefits to turf, soil, and water quality have not been evaluated similar to the evaluations of composted municipal biosolids (CMB) (Barker, 2001). Comparisons between CMB and CDM are needed. In addition, drawbacks to manure transported through sod could necessitate changes in manure management and TMDL implementation. Both benefits and drawbacks need to be studied for evaluation of systems for manure use and export through sod.

LITERATURE REVIEW

Soil Physical and Chemical Properties

Soil physical and chemical properties are influenced by many anthropogenic activities, including surface or incorporated applications of manure. In the Great Plains region, effects of beef cattle manure on soil hydrological properties were examined on a clay loam soil (Miller et al., 2002). The test site was a field that received one, two, or three times the recommended rates of manure applications in 1974. The increasing manure rates increased soil water retention 5 to 48%, water content 10 to 22%, and ponded infiltration rates more than 100%. In addition, saturated hydraulic conductivity increased 76% due to an increase in macropore size. Applied to establishing turf, mixing 30 % by volume of CMB enhances physical properties of sandy soils, including significant increases in soil water-holding capacity (Cisar 1994).

In order to attain a high level of soil quality for plant production, including turfgrass, manure application must facilitate positive changes in chemical as well as physical properties of soil. Positive impacts of manure on both soil physical and chemical properties can occur during both short and long-term applications. Wood and Hattey (1995) documented build-up of soil organic matter, increased soil fertility, and improved soil physical properties in response to application over periods of 50 to 100 years. Eghball (2002) examined short-term soil responses to manure or compost applied at rates that met nitrogen requirements for *Zea mays* L.. Bulk density was unaffected by either raw or composted manure during annual applications over 4 years. Yet, the manure rates needed to meet N requirements of *Zea mays* contributed a substantial surplus of total soil phosphorus, nitrogen, and other ions during each yearly application. In addition, soil pH in the top 15 cm of soil in plots receiving N-based manure and compost rates increased compared to an unfertilized control. In contrast, soil pH decreased in plots fertilized with NH_4-N. Eghball (2002) concluded that changes in total N and P concentrations in soil were greater for N-based than P-based manure application rates. In addition, P-based manure applications yielded greater concentrations of total N and P in the soil than conventional inorganic fertilizers.

Soil Biological Properties

Manure applications can similarly improve soil biological properties. For example, Wood and Hattey (1995) identified beneficial changes in microbial populations after manure applications. Increasing rates of cattle slurry increased microbial biomass over a 30-year period. In addition, increasing rates of solid cattle manure greatly increased populations of heterotrophic bacteria and actinomycetes (Wood and Hattey, 1995). Furthermore, cattle manure increased vesicular-arbuscular (VA) mycorrhiza colonization and populations of free-living, N_2-fixing cyanobacteria (blue-green algae).

In addition to increasing populations and biomass, organic amendments can change microbial community structure and function in soil. Manure effects on both microbial biomass and community structure were observed in treatments applied to corn (*Zea mays L.*) rotated with crimson clover (*Trifolium incarnatum* L.) and annual ryegrass (*Lolium multiflorum* L.) (Peacock et al., 2000). Treatments comprised an unfertilized control, ammonium nitrate, and two manure rates. Phospholipid fatty acid (PLFA) analysis indicated microbial biomass increased within the 0 to 5 cm depth of manure treatments, but not in control and fertilizer treatments. In addition, changes in microbial community structure and total C and N concentrations in soil were observed in manure treatments compared to the control and fertilizer treatments (Peacock et al., 2000).

Microbial community changes were observed in the aforementioned papers as a result of fresh manure applications, but either fresh or composted animal manure can increase microbial populations. Microbial changes occurring over periods of 40 years provided evidence of long-term effects of fresh manure (Wood and Hattey 1995). Similarly, composted cattle manure rates of 5 and 15 % (wt wt^{-1}) during a 30-year-old N-management experiment increased microbial populations compared to unamended soil (Hadas et al., 1996).

Microbial population and function can change during short-term manure applications similar to long-term manure applications. Short-term responses of soil microbial communities to three fresh manure treatments (none, swine, and dairy), three soils, and two moisture regimes were observed by Larkin et al. (2002). Soils were incubated with manure treatments for four drying cycles (1200-1500 degree days) and sampled before and after drying cycles. Swine and dairy manure treatments increased microbial populations in all soils. Fungal populations were increased in the swine treatment only. In addition, substrate utilization profiles and fatty-acid-methyl-ester profiles indicated a distinct change in community function as a result of swine and dairy manure applications. Yet, soil type was the main factor that influenced microbial community structure.

Phosphorus additions can facilitate changes in microbial biomass and structure like applications of fresh animal manures. Continuous corn and rotation of corn with crotalaria (*Crotalaria grahamiana* Wight and Arn) were compared with and without P fertilizer (0 and 50 kg P ha^{-1}) in Kenya soils (Bunemann et al., 2004). Using phospholipid fatty acid analysis, the authors showed differences in microbial community function between continuous corn and the rotation were greater than between the P fertilizer treatments. Yet, microbial community structure differed between the P fertilizer rates in continuous corn (Buenemann et al., 2004).

Like P applications on continuous corn, N applications can stimulate microbial population growth and changes in community function. Long-term organic N applications affected soil microbial dynamics more than short-term inorganic N applications in pots of corn over 306 days (Fauci and Dick, 1994). The pots contained four soils from long-term field plots amended with beef manure, pea (*Pisum sativum* L.) vine residue, and 0 or 90 kg N ha^{-1} biennially for 59 years. In addition, four organic residues and four inorganic N rates were mixed with soils in pots. Recent organic inputs to pots increased microbial biomass C up to 4 times more than control pots receiving inorganic N inputs (Fauci and Dick, 1994). Yet, microbial biomass increases in response to short-term manure applications declined over the 306 days of the experiment. In contrast, a gradual buildup of microbial biomass over the 306 days of corn growth was observed for soils that received organic applications for 59 years prior to the short-term additions made to pots. Applications of manure to soil for many years compared to one-time applications appears more beneficial for sustaining microbial biomass.

Soil Leachate

The rates of manure needed to meet plant P or N needs can contribute to environmental hazards, including leaching of N and P into groundwater sources. At large rates, P can be transported in percolate from the surface layer of soil types with limited P-sorption capacities into subsoil layers. In a Dothan soil in Alabama, excess P moved past the surface to a depth of 15cm (Lund and Doss, 1980). However, in a Lucedale soil, P-sorption and accumulation in the surface layer prevented leaching losses after 3 years of surface application of fresh manure (Lund and Doss, 1980).

The P-sorption characteristics of soils are affected by mineralogical properties. James et al. (1996) used confined production sites of turkey and beef to assess potential P leaching from calcareous soils. Soils were sampled in 30-cm increments down to 210 cm or to a limiting layer. Large amounts of extractable organic P in surface layers of soil decreased to background levels within 2 to 3 years after manuring ceased due to plant uptake. However, in heavily manured fields, extractable inorganic P levels well above background concentrations were observed as deep as 210 cm. Due to the high retention of P in soil, there was little risk for groundwater contamination (James et al., 1996).

Compared to inorganic P sources, total P concentrations in manures are relatively low. The low concentrations are expected to limit leaching losses from manure compared to inorganic P applications. In addition, dairy-manure P can be in a recalcitrant form, which allows accumulation in soils over repeated applications (Heckrath et al., 1995). Heckrath et al. (1995) sampled drainage pipes from the

Broadbalk continuous wheat experimental plots in Rothamsted UK to evaluate P leaching loss. Treatments comprised no P, inorganic superphosphate, and farmyard manure additions over a 150-year period. Soil extractable P concentrations in the inorganic P treatments were greater than plots that received farmyard manure applications. In addition, Heckrath et al. (1995) fractionated soil P into three components: dissolved reactive P (DRP), total particulate P (TPP), and dissolved organic P (DOP). The DRP concentration was highest in the leachate, while TPP and DOP concentrations ranked second and third. Yet, DRP was not the greatest concentration compared to TDP and DOP in soil. These data indicate multiple forms of P exist in manure and soil and need to be quantified to accurately assess P leaching.

The soluble P fraction in animal manure poses the greatest threat to the environment. Sharpley and Moyer (2000) used a modified Hedley fractionation and release during simulated rainfall to investigate relative solubilities of P in raw and composted manures. Twenty-four manures, including raw and composted dairy and poultry manures, poultry litter, and swine manure were collected. Typically, most of the P in the manure sources was inorganic. Of the inorganic P fraction, 80 % was water soluble (Sharpley and Moyer, 2000). However, total and water soluble P in dairy manure was typically lower than swine and poultry composts and manures (Sharpley and Moyer, 2000). The relationship of water soluble P to leaching loss from the manure sources indicated water soluble P was a good indicator of potential P leaching loss from applications of animal manures.

Water soluble P can pose the greatest threat to groundwater contamination, yet other forms of P are mobile as well. Eghball et al. (1996) observed this trend in a study using soil samples from a long-term cropping systems study. In 1953, plots were divided into manure (27 Mg ha^{-1} annually) and no manure sections to which fertilizer was applied and corn was grown. Soil samples were collected to a depth of 1.8 m. Manure applications increased extractable P concentrations at greater depths in the profile than conventional fertilizer applications (Eghball et al., 1996). The authors concluded that manure P could have moved in organic forms or chemical reactions within the manure may have enhanced P solubility and leaching (Eghball et al., 1996). The fractions of P transported through soil in leachate need to be quantified to evaluate environmental impacts of manure applied to cropland, including turfgrass.

Municipal biosolids are more commonly applied to turfgrass than animal manures and can pose a similar threat to groundwater. Laboratory and greenhouse studies were conducted to evaluate P forms and leachablity of eight biosolid products, chicken manure, and commercial fertilizer (Elliot et al., 2002). Most of the P lost in leachate was inorganic and losses from biosolid P sources were less than fertilizer P sources. The authors concluded P movement could be highly correlated to a phosphorus saturation index of the biosolid used. The higher the phosphorous saturation index of biosolids, the greater the probability of P movement through the soil profile (Elliot et al., 2002).

The P saturation index of biosolids are related to concentrations of Fe and Al oxides, which can retain P against leaching (Elliot et al., 2002). Reaction of inorganic P with the metal salts can reduce soluble P concentrations and increase the P retention in soil. Lu and O'Connor (2000) examined the effects of biosolid applications on P retention in Florida soil through a series of single-point isotherms. Applications of biosolids high in Fe and Al salts increased P retention in soils low in extractable Fe and Al. Biosolid applications did not increase P retention in soils that were high in Fe and Al (Lu and O'Connor, 2000). Phosphorus in biosolids containing abundant Fe and Al could be a slowly available P source with little leaching loss compared to soluble P sources.

Plant Growth and Nutrition

Applications of biosolids can enhance crop growth. Surface applied dairy manure increased growth and yield of coastal bermudagrass (Lund and Doss, 1980). Yields were significantly higher for every manure treatment compared to the control plot. The greatest yield response was observed for the highest manure rate applied as liquid. In addition, manure applications increased K, Mg and pH in the subsoil, which could have increased yields as well (Lund and Doss, 1980).

Though biosolid applications can increase plant yields, supplemental inorganic nitrogen fertilization may be required. According to Cisar (1994), CMB applications on turf need to be combined with N fertilizer. Although applications of CMB to turf may not replace conventional fertilizer, diverting solid waste streams from urban land fills to turf can minimize environmental costs for cities.

If manure and CMB are to be applied and recycled through turf, responses of turf, soil, and water quality need to be quantified. Responses of soil physical and chemical properties to manure and CMB are expected to benefit turf growth. In addition, manure and CMB could affect microbial populations and community function within the soil layer of sod. Despite potential benefits, current concerns about non-point source losses of P from both agricultural and urban watersheds need to be related to rates and concentrations of P forms in compost sources, compost-amended soil and sod.

Objectives

1. Evaluate effects of increasing rates of composted dairy manure and composted municipal biosolids on soil physical, chemical, and biological properties within and below turfgrass sod layer.
2. Evaluate effects of increasing rates of composted dairy manure and composted municipal biosolids on P and N leaching during turfgrass establishment.
3. Relate turf growth and quality to observed changes in physical, chemical, and biological properties of soil in and below the sod layer.

MATERIALS AND METHODS

Experimental Design

Experiment 1

Four replications of a factorial design comprising two turf species (Raleigh St. Augustinegrass and Tifway 419 Bermudagrass), three rates of composted manure, and three soil textures were used to evaluate responses of turf, soil physical and chemical properties, and leaching losses during turfgrass establishment. The three manure rates comprised a control (no manure) and two rates of P applied as composted dairy manure (200 and 400 kg P ha^{-1}). Each manure rate was incorporated within a packed surface layer (10-cm depth) of each soil. A sand (96% sand, 2% silt, and 2% clay), loam (Windthorst fine sandy loam), and clay (Houston black clay) soil texture were used in the surface layer and within a 60-cm depth of subsurface soil in 10-cm diameter PVC columns. Columns were constructed and placed in a greenhouse in March 2003 at Texas A&M University in College Station.

Experiment 2

A modified repetition of experiment 1 was conducted. Three volume-based rates of a CMB (Dillo Dirt^{TM}, City of Austin, Austin, TX) and CDM were imposed on three soil types for a single turfgrass species (Raleigh St. Augustingrass). The same control was utilized for CDM and CMB. The volume-rates of compost sources; 0, 150 cm^3 L^{-1}, and 250 cm^3 L^{-1} represented current recommendations of the City of Austin and the U.S. composting council (City of Austin, 2001 and US Composting Council, 1999).

Microbial Pot Experiment

A separate pot study was conducted during experiment 2. Three replications of a factorial design comprising two compost sources and two compost rates were used to evaluate responses of microbial populations and community function during turfgrass establishment. Composted dairy manure and CMB were incorporated at the high volume-rate (250 cm^3 L^{-1}) and compared to the 0-rate in 30-cm pots of each soil. Once treatments were incorporated, pots were sprigged with St. Augustinegrass.

Lysimeter Construction and Management

Experiment 1

The surface layer and 10-cm increments of subsurface layers were weighed and firmed within columns using a piston and weighted hammer (1 kg). The weighted hammer was dropped three times from a 30 cm height. Turfgrass plugs (10 cm diameter) were planted after the surface layer was firmed. Plugs were washed with distilled water to remove soil and were weighed before planting. A drainage cavity and port at the base of the columns was used to deliver hydraulic pressure for initial hydration of columns and for collection of leachates after irrigation events. The turf surface was watered daily to balance evapotranspiration. Turfgrass was clipped to maintain a 5 cm canopy height and clippings were collected, dried, and weighed throughout the experiment to quantify growth rates and nutrient uptake.

A 9-cm (700 ml) depth of distilled water was applied 4, 8, and 12 weeks after sprigging to achieve water flow through columns, leachate collection, and measurement of water infiltration rates. Additional water applications to the clay filled columns were made until water flow and leachate collection were achieved on all three dates. Water infiltration rates were measured when water level reached 5cm above soil surface. After the third leaching, soil columns were cut into depth increments starting at the base of the surface or treatment layer (10-cm depth) and sampled. The surface layer was longitudinally split to quantify soil physical and chemical properties with and without turfgrass roots.

Experiment 2

Procedures were similar to Experiment 1, except the soil depth below the treated layer was reduced to 40 cm. The depth of sampling for the surface layer was increased to 12-cm. In addition, the amount of water added to columns for each leaching event represented one pore volume for the soil type contained within each lysimeter. Pore volumes were determined using average bulk densities for the three soils from Experiment 1 and a particle density of 2.65 g cm^{-3}. The estimated pore volumes were 1200 mL for the sand, 1500 mL for the loam, and 1600 mL for the clay.

Sampling and Analysis

Sampling and analysis were similar among Experiments 1 and 2. Manure, CMB, and soil sampled at the start of the experiment were digested and analyzed to determine total N through an autoanalyzer and total P through the ICP (Parkinson and Allen, 1975). In addition, NO_3-N was extracted in 1 N KCL and determined through cadmium reduction with an autoanalyzer (Dorich and Nelson, 1984). Compost P was extracted in acidified NH_4OAc-EDTA and measured using an ICP (Hons et al., 1990) prior to application to lysimeters.

Wet and dry weights of soil depth increments were measured to compute bulk density and soil water content after the final leaching event. Soil samples were analyzed to determine pH, salinity, extractable P (Hons et al., 1990), NO_3-N through cadmium reduction (Dorich and Nelson, 1984), and water soluble P at the end of both experiments. Water soluble P was measured for the surface layer only. Total soil organic matter was determined gravimetrically through ignition in a muffle furnace at 550^0C for 16 hrs. Dry weights of clippings were measured and composited over all dates for subsampling, digestion, and analysis of total P and total N. Total N was analyzed using an autoanalyzer (McGeehan and Naylor, 1988) and total P was determined through use of an ICP.

Leachate samples were vacuum filtered through a 0.45 µm sterile membrane. Leachate samples were analyzed for molybdate reactive P through the colorimetric malachite green method on a microplate reader (Dynex Technologies, Chantilly, Virginia) (D'Angelo et al., 2001). Nitrate-N in leachate was measured using cadmium reduction (Doric and Nelson, 1984). Total P, Ca, Mg, K, Na, S, and B of leachates were measured through an axial ICP.

Microbial Sampling and Analysis

Experiment 1

All soil microbial measurements were based on 12 subsamples of two replications of the 0- and 400-kg P rate for each soil in the experimental design outlined above. The microbial sampling was done before treatment application and turfgrass sprigging and after completion of the third leaching event. Microbial populations were estimated by serial dilution of 10-g soil samples plated on 10 % Tryptic Soy Agar for total bacteria and Rose Bengal Streptomycin Agar for total fungi. Community differences in substrate utilization were determined on BIOLOG GN2 plates (BIOLOG Inc., Hayward, CA) adapted from Garland and Mills (1991). Average well-color development (AWCD) calculated as the average optical density across all wells/plates, was used as an indicator of general microbial activity. The AWCD was used as covariate data for Principle Component Analysis (PCA) to determine differences in microbial community function (carbon source utilization) (Zak et al., 1994).

Experiment 2

Microbial populations were enumerated four times during turf establishment in pots for the second experiment. Samples for microbiological assays were taken with a 1.27-cm soil probe, composited among reps for each treatment, and prepared according to the aforementioned procedure in the first experiment.

Statistical Analysis

The Statistical Analysis System (SAS Institute 1993) was used to analyze both experiments. Soil type, grass species, amendment rate, or compost source were treated as main effects and class variables in the model. Leaching events and soil depths were analyzed separately. Due to poor growth of bermudagrass in Experiment 1, the two grass species were analyzed separately and data for St. Augustinegrass only was presented. The Generalized Linear Models procedure was used to assess variation of NO_3-N, total P, and molybdate reactive P in leachate samples. Analysis of variance procedures (ANOVA) were used to assess variation of bulk density, infiltration rate, water holding capacity, and colony counts ($\log_{10}$ values). In addition, the ANOVA was used to analyze soil nutrients separately for each depth. Fisher's least significant difference (LSD) was used to compare means of rates, soil types, and compost sources. When interactions between soil and rate or soil and compost source were significant ($P=0.05$), soils were analyzed separately.

RESULTS

Experiment 1

Physical Properties

Although increasing CDM rates increased total soil organic matter ($P=0.001$) (Table 1, Appendix B), water infiltration rate, bulk density at the start and end of the experiment, and water holding capacity were not different among CDM rates. In contrast, the three physical properties varied ($P=0.01$) among soil types. Water infiltration rate was least for the clay and greatest for the sand (Table 2, Appendix B). Bulk density was lowest for the clay, and highest for the sand (Table 2, Appendix B). Conversely, water content of soil near field capacity was greatest for the clay and smallest for the sand ($P<0.001$) (Table 2, Appendix B).

Chemical Properties of CDM

Total P and N concentrations in the CDM were 4554 mg N kg^{-1} and 3450 mg P kg^{-1}. Extractable NO_3-N and P were analyzed to quantify plant-available forms. Extraction in 1M KCL provided estimates of NO_3-N concentrations (7 mg kg^{-1}) in CDM. Extraction of CDM in NH_4OAc-EDTA indicated 52% of the total P concentration was available to turf roots (1777 mg kg^{-1}). Nutrient additions for each column were high as well (Table 3, Appendix B).

Chemical Properties of Soil

Although the CDM applied to supply the two P rates contained 4554 mg total N kg^{-1}, soil NO_3-N concentration was similar among CDM rates in the treatment layer at the end of the experiment. Nitrate-N concentration did not vary among depths either. In contrast, NO_3-N concentration did vary ($P=0.001$) among soil types in the treatment layer. Mean soil NO_3-N concentration for all depths was 6 mg kg^{-1} for the clay, 4.3 mg kg^{-1} for the loam, and 3 mg kg^{-1} for the sand.

Extractable P concentrations differed ($P< .0001$) among CDM rates in the 0 to 10 cm layer of all three soils (Table 4, Appendix B). At depths below 10 cm, extractable P was similar among rates for all soil types. Increasing rates of CDM did not increase extractable P concentrations at depths below 10 cm.

Similar to NH_4OAc-EDTA extractable P, water extractable P in the 10 cm treatment layer was ($P< .0001$) different among rates of CDM (Table 5, Appendix B). The increase of water extractable P for each rate of total P indicated an increased potential for P transport in soil solution to deeper depths (Sharpley and Moyer 2000). In addition, soil type ($P<0.001$) affected water extractable P. Yet, there was not an interaction between CDM rate and soil type.

Soil Leachate

Considering the amount of nutrients applied in the form of CDM, nutrients could be lost through leachate. Both CDM and NO_3-N fertilizer (50 kg N ha^{-1}) provided N during turf establishment in the column lysimeters. For leaching events 1 and 2, the two CDM rates did not ($P=0.05$) increase NO_3-N concentration in leachate from the columns. Soil type was the only factor that influenced NO_3-N leaching during leaching events one ($P= 0.003$) and two ($P=0.01$). Respective mean NO_3-N concentrations in leachate during leaching events 1 and 2 for the sand, loam, and clay were 6 mg L^{-1}, 20 mg L^{-1}, and 44 mg L^{-1}.

During the third leaching event, NO_3-N concentrations in leachate from the highest and lowest CDM rate (400 kg P ha^{-1}) were greater than the control (P=0.03) (Table 6, Appendix B). Variation among leachate volumes collected confounded variation of NO_3-N concentration in leaching events 1 and 2. Thus, when NO_3-N losses were computed there were no significant differences among rates for all leaching events (Table 7, Appendix B). Soil type was the only factor influencing NO_3-N loss from the columns. Mean NO_3-N losses for all three leaching events were 3 times greater for the clay than the loam and 37 times greater than the sand.

The P leached from columns was attributed to CDM or desorption of P from soils in columns. Variation of volumes of leachate from columns confounded variation of TDP concentration. Analysis of concentrations and mass loss of P in the leachate indicated no differences among the three CDM rates occurred for all three leaching events (Tables 8 and 9, Appendix B). In contrast, soil type did (P=0.03) affect P loss in all three leaching events.

Turfgrass Growth and Nutrition

Growth rates of St. Augustine turf were (P=0.03) greater for soil amended with 400 kg P ha^{-1} applied in CDM than the control for the June and July measurements (Fig 1, Appendix A). Bermudagrass growth rates were slow and did not differ among CDM rates. Shading within columns may have limited bermudagrass growth.

Growth rates were affected by CDM, but nutrient concentrations and nutrient content in the plant were not different among rates of CDM. Mean concentrations among CDM rates in dry plant tissue were 23 g total N kg^{-1} and 2.6 g total P kg^{-1}.

Fertilizer N applications minimized potential variation among soil types of TKN in clippings, but low P in the sand was expected to limit P concentrations in clippings. Mean P content of clippings was 7 g for the sand, 14.3 g for the loam, and 11.1 g for the clay. The sand was not different from the clay, but was different (P=0.03) from the loam.

Microbial Populations and Community Structure

Microbial populations are typically high under turfgrass systems (Bigelow et al., 2002). The continual degradation of roots provides a renewable source of carbon for microbes. As a result, microbial populations were extremely high and similar among rates of CDM. Fungal and bacterial counts averaged 1.8 x 10^4 and 5.6 x 10^7 colony forming units (cfu), respectively, for the contrasting CDM rates and all three soils during the first experiment.

Community function was different between columns with and without CDM. A principle component analysis (PCA) of substrate utilization profiles indicated microbial community function did shift when CDM was applied (Fig 2, Appendix A). If community function differed, the PCA would reveal distinct groupings between treatments without manure in one quadrant of the plot and treatments with manure in another quadrant of the plot. In the PCA plot, all but point 10 of the manured treatments segregated to the left side and the non-manured treatments to the right side. This indicates that microbial community structure was affected by CDM applications, yet this analysis does not reveal what processes were affected by the change.

Experiment 2

Physical Properties

In the second experiment, large volume-based application rates were used. Prior to turfgrass establishment and packing of soil, incorporation of CMB decreased bulk densities in all three soils (Table 10, Appendix B). Yet, rate or compost source did not affect bulk density, water holding capacity, or water infiltration rate at the end of the experiment. Similar to Experiment 1, soil physical properties varied ($P=0.002$) among the three soil types (Table 2, Appendix B). Bulk density was highest for the sand and lowest for the clay. Similarly, water infiltration rate was greatest for the sand and lowest for the clay (Table 2, Appendix B). Conversely, gravimetric water content was greatest for the clay and least for the sand (Table 2, Appendix B).

Although physical properties at the end of Experiment 2 were similar among rates of CDM and CMB, increases in total organic matter occurred among the three rates in the surface layer of the sand and loam (Table 11, Appendix B). An interaction ($P=0.02$) between application rate and soil was evident in a lack of rate effects on organic matter in the clay. Structural water in the smectitic clay contributed to large weight losses on ignition, which limited the utility of this method for total organic matter determination.

Chemical Properties of Compost

Composted dairy manure and CMB supplied different amounts of nutrients in the volume-based applications made in this study. The nutrient concentrations ± standard deviations in CMB were 17.5 ± 0.4 g total N kg^{-1} and 16.1 ± 0.5 g total P kg^{-1}. The total

N and P concentrations in CDM were 6.2 ± 0.8 g kg^{-1} and 3.5 ± 0.3 g kg^{-1}, respectively. Extractable values of P for CDM (1.8 ± 0.7 g kg^{-1}) were higher than CMB (1.1 ± 0.6 g kg^{-1}). In contrast, extractable NO_3-N concentrations for CMB (23 mg kg^{-1}) were greater than CDM NO_3-N concentrations (7 mg kg^{-1}). Water extractable P was 3 times greater for CDM (460 mg kg^{-1}) than for CMB (120 mg kg^{-1}). Substantially smaller rates of extractable P were applied in CMB than CDM. (Table 3, Appendix B).

Chemical Properties of Soil

Total N and P content in the surface layer decreased substantially from the start of the experiment, indicating some mineralization occurred (Table 12, Appendix B). In addition total N and P varied among increasing rates of biosolid application and biosolid source (Table 12, Appendix B). Yet, there was not a significant interaction between application rate and biosolid source. The CMB contained more total N and P, therefore CMB at both rates were higher than CDM at both rates (Table 12, Appendix B) When CDM and CMB were applied at large volume-based rates, soil NO_3-N concentration of the treatment layer varied ($P=0.02$) among rates at the end of the experiment. The concentrations of NO_3-N were different among all three rates of CMB or CDM for the top 12 cm of soil (Table 13, Appendix B). Soil NO_3-N did not significantly vary among CDM or CMB rates below 12 cm. The soil NO_3-N concentrations were similar between compost sources even though CMB contained more total N (17.5 g total N kg^{-1}) than CDM (6.2 g total N kg^{-1}). In addition to compost N, inorganic N fertilizer was applied (Table 3, Appendix B).

Increasing volume-based rates increased extractable P concentrations in the surface layer of all three soils. The Fisher's LSD test indicated extractable soil P concentrations differed ($P=0.05$) among all three rates in the 0 to 12-cm depth (Table 14, Appendix B). In addition, there was an ($P=0.002$) interaction among soil type and compost source for depths below 12 cm. In the sand, extractable P concentrations significantly varied among CDM and CMB rates below the 12-cm depth (Table 14, Appendix B). In addition, P concentration varied among CDM and CMB rates for the loam and clay at the 12 to 22 cm depth. Greater mean total P concentrations in CMB (16 g total P kg^{-1}) compared to CDM (3.4 g total P kg^{-1}) were associated with larger increases of extractable soil P for CMB in the surface layers of the sand and loam.

Applications of CDM and CMB at volume-based rates increased water extractable P in the 0 to 12 cm treatment layer ($P=0.002$). Except for CMB applied to sand, water extractable P concentrations were greater for rates of 250 cm^3 L^{-1} and 150 cm^3 L^{-1} than for the 0 rate (Table 15, Appendix B).

Soil Leachate

Leaching events were analyzed separately in this study. Leaching losses of NO_3-N were ($P=0.002$) affected by the large, volume-based application rates in combination with NO_3-N fertilizer applications. Soil types were analyzed separately to accommodate an interaction between soil type and biosolid rate during each leaching event ($P=0.03$). Compost source did not ($P=0.05$) affect NO_3-N concentrations in leachate, but leachate NO_3-N concentrations differed among CMB rates during leaching date 1 for both the sand and loam. In contrast, leachate collected from the columns filled with clay was affected by rate during leaching event 3 only (Table 16, Appendix B). The two rates of CDM and CMB were different from the control on leaching dates 2 and 3 for the sand (Table 16, Appendix B).

During leaching event 1, CMB and CDM applications did ($P=0.02$) increase NO_3-N loss from the three soil types (Table 17, Appendix B). Incorporation of CDM or CMB in each soil did not ($P=0.05$) affect NO_3-N loss during leaching events 2 and 3. Volumes collected were highly variable during leaching events 2 and 3, which resulted in no differences among rates in leaching events 2 and 3. In contrast to NO_3-N concentrations, there was not an interaction between application rate and soil type for NO_3-N losses.

Applications of different rates of CDM and CMB caused a ($P=0.03$) soil type by rate interaction for P loss in leachate. Increasing CDM and CMB rates did not affect leachate P loss from the loam and clay. In contrast, leachate P loss increased substantially for all leaching events when CDM or CMB was applied to sand (Table 18, Appendix B). Rates of CDM and CMB (150 and 250 $cm^3\ L^{-1}$) were not different from each other, but were ($P=0.01$) greater than the control (0 $cm^3\ L^{-1}$) for all leaching events for the sand (Table 18, Appendix B). The CDM yielded significantly ($P=0.01$) greater P losses in leachate compared to CMB in leaching event 1, which was associated with a greater concentration of water soluble P in CDM compared to CMB. Phosphorus concentrations in leachate were affected by CMB and CDM incorporations similar to P leaching losses (Table 19, Appendix B).

Applications of CMB and CDM significantly affected MRP in leachate as well. Composted dairy manure treatment yielded greater (P=0.05) losses of MRP in leachate than losses observed from CMB treatments applied to the sand (Table 19, Appendix B). In addition, applying CDM or CMB significantly increased MRP losses in leachate compared to the 0 rate in the sand (Table 20, Appendix B). Of the total dissolved P lost in leachate from sand, 37 to 98 % of P was MRP. In addition, greater MRP losses in leachate for CDM treatments indicated that concentrations of water soluble P in CDM were greater than in CMB.

Turfgrass Growth and Nutrition

Growth rates of St. Augustinegrass were similar among compost sources and rates in the second experiment. Despite greater nutrient additions during the second experiment, there were no differences (P=0.2) in nutrient concentrations in tissue among compost source or rates. Inorganic fertilizer applications reduced variation among rates of TKN in plant tissues, but low extractable P concentrations in the sand and loam were expected to limit growth. Nevertheless, this was not observed in this experiment. Average plant tissue concentrations for the second experiment, of total N and total P were 28 g total N kg^{-1} and 3.1g total P kg^{-1}.

Nitrogen and Phosphorus Recovery

Most of the P recovered at the end of the experiment was located in the top 12 cm of soil. Except for the sand, more P was removed in St. Augustinegrass turf than through leaching. Though incorporation of CMB and CDM did increase P leaching loss compared to the control in sand, most of the P applied was retained in soil. In the case of the loam and clay soils, leaching losses were negligible, indicating most of the P was retained in soil (Fig. 3, Appendix A). In contrast to P, more NO_3-N was lost in leachate compared to clipping removal in the loam and clay soils. The loam and clay soils contained greater initial total- and NO_3-N than the sand, which may have been lost in leachate or recovered in depths below 12 cm (Fig. 4, Appendix A). A considerable amount of N mineralization occurred, yet nutrients collected at the end of the experiment ranged from 69 to 85 % of that at the start (Fig. 5, Appendix A). Similarly, P mineralization did occur and the nutrients recovered at the end of the experiment ranged from 55 to 85 % of that at the start (Fig 6., Appendix A). The greatest mineralization of N and P occurred in the highest rate of CMB columns, which could be related to greater soil extractable N and P concentrations measured at the end of the experiment for the CMB columns. Yet, there was no indication of greater leaching loss from these columns.

Microbial Populations and Community Structure

Similar to experiment 1, applications of CMB or CDM at volume based rates did not alter microbial populations. Fungal and bacterial counts averaged 2.5×10^4 and 3.3×10^7 cfu respectively for the contrasting CDM and CMB rates and all three soils. In contrast to experiment 1, microbial community function was unaffected by compost source or rate. All principle component analysis plots were similar for the four sampling dates, which showed little difference among rates (Fig 7, Appendix A).

DISCUSSION

Physical and Chemical Properties

It was originally hypothesized that applications of P-based rates of composted dairy manure (CDM) would enhance soil physical properties. Though the two rates of CDM applied high P rates (200 and 400 kg P ha^{-1}), soil physical properties were not enhanced. According to Cisar (1994), a large volume-based rate (300 cm^3 L^{-1}) of composted municipal biosolids was needed to affect water holding capacity. Similarly, the city of Austin recommends incorporation of 15-33% by volume of their composted municipal biosolid product (Dillo Dirt^{TM}) to enhance soil physical properties within depths to 15 cm (City of Austin, 2001). In the first experiment, approximately 8% by volume was applied as CDM at the highest P rate utilized, which is substantially lower than rates recommended by Cisar (1994) and the City of Austin. Yet, when CDM or CMB was applied at large, volume-based rates, soil physical properties were unaffected at the end of the experiment. These data indicated the rates were not high enough to alter specific properties or bulk density and other properties of CDM and CMB were similar to soil. Research conducted by Provin et al., (2003) showed differences in bulk density due application of biosolids 330 d after application of biosolids, but not after 60 d. In addition, bulk densities computed before turfgrass establishment and packing indicated CDM has properties similar to soil. Whereas, the CMB decreased bulk density indicating that packing the soil may have negated the effects of CMB applications. Although the P-based rates of CDM in Experiment 1 did not alter physical properties, substantial rates of total P and N were applied.

The extractable NO_3-N concentrations in Experiment 1 were not different among soils amended with high P based-rates of CDM and sampled after the third leaching event within the depth of incorporation even though 363 and 726 kg total N ha^{-1} was supplied. Only a small fraction of the total N applied as CDM is NO_3-N (7 mg NO_3-N kg^{-1}). Thus, NO_3-N concentrations in soil ranged between 2 and 8 mg kg^{-1}, which was not enough to sustain turfgrass growth. Typical annual N application rates for St. Augustinegrass are applied in split applications totaling 195 kg N ha^{-1} for home lawn use (Turgeon 1999). Inorganic N applications are necessary to supplement NO_3-N available in compost and to sustain adequate turfgrass growth. The low CDM and CMB contributions of NO_3-N in this study are consistent with Cisar's (1994) recommendation that N fertilizer applications were necessary to produce high quality and harvestable St. Augustinegrass sod on CMB-amended soil.

Many composted products tend to have high inorganic P amounts that are plant available. Sharpley and Moyer (2000) found composted materials to contain 63 to 92% inorganic P, which would increase extractable P levels when applied to soil. Of the total P concentrations in CDM, 52 % was extractable in acidified NH_4OAc-EDTA in Experiment 1. Increases in extractable P in the depth of incorporation were attributed to high extractable P amounts measured in CDM. Applications of CDM increased extractable soil P levels for the sand from 2 mg kg^{-1} to 110 mg kg^{-1} in Experiment 1. Thus, CDM incorporation in sand increased soil P from initial levels by 5,400 %. In addition, of the total amount of extractable P applied in Experiment 1 approximately 70

% was retained in the top 10 cm in the sand. Although extreme amounts of P are being applied in CDM, most of the P is retained in soil.

Similar to the P-based rates of CDM applied in Experiment 1, the large volume based rates of CMB and CDM increased P concentrations of the surface layer during Experiment 2. Total P applied to the columns was much greater compared to the initial experiment. In contrast to Experiment 1, the high rates significantly increased NO_3-N concentration in the top 12-cm of soil. Similar rates were used by Barker (2001) on perennial ryegrass and similar extractable N and P values were documented. Though a statistical analysis was not conducted to compare soil NO_3-N concentrations between the two experiments, average concentrations were similar between experiments 1 and 2 in the surface layer.

Applications of CDM or CMB at the rates used in this study to lawns or sod of St. Augustinegrass or other species could eliminate the need for additional inorganic P applications to maintain healthy turfgrass. The application rates of manure supplying 200 kg ha^{-1} and 400 kg ha^{-1} of total P are high compared to typical fertilizer P rates applied to turfgrass. Likewise, the volume based rates of compost used to improve soil physical properties supply large amounts of total N and P. Phosphorous applications are typically recommended for St. Augustinegrass when soil test P is inadequate to support healthy turf (Turgeon 1999). Phosphorus deficiencies are most evident during turfgrass establishment, but only 34 kg P ha^{-1} of available soil P is considered adequate for turfgrass growth (Turgeon 1999). If St. Augustinegrass removed P at rates (~14.2 mg P yr^{-1}) similar to this experiment, it would take eight years to deplete the extractable P concentrations available when 400 kg total P ha^{-1} is applied to sand if clippings were removed. Moreover, it will take 14 yrs to deplete the 208 mg kg^{-1} of extractable P provided in volume-based rates of CMB added to sand if clippings were removed.

Leachate Components

Phosphorus

If the majority of P is inorganic in composted materials, including a large fraction that is water soluble and vulnerable to leaching loss, then negative environmental impacts of CDM applications are possible (Sharpley and Moyer, 2000). Yet, leaching loss from well drained soils was not evident during the first experiment even though 270 mm or more of water was applied in addition to irrigation that balanced evapotranspiration. These results suggest an application of up to 400 kg manure P ha^{-1} would not contribute to leaching losses when CDM rates are incorporated in soil during sod establishment. Furthermore, CDM applications can replace inorganic P rates during turfgrass establishment and over the long-term after turfgrass establishment. Moreover, Elliot et al. (2002) used similar P rates applied as biosolid products and leachate losses were similar to losses observed in this study. In addition, Elliot et al. (2002) compared inorganic P applications to biosolid P applications and observed significantly greater P losses from inorganic P applications at similar rates.

When volume based rates were used, leaching losses occurred in the sand. Leaching losses of P in both experiments were similar to losses recovered by Easton and Petrovic (2004) during seeding of perennial ryegrass. In addition, leachate losses of total dissolved P and molybdate reactive P (MRP) were greater for CDM than CMB. Water extractions of CDM and CMB yielded greater concentrations of water soluble P in CDM than for CMB. Yet, total P lost in leachate ranged from 0.9 to 4.6 % of the total P applied to the sand. According to Elliot et al. (2002), when triple super phosphate was applied at similar rates losses range from 1.7 to 21.7 % of the total amount applied.

Concentrations exceeding 20 μg total P L^{-1} can cause eutrophication of lakes, which were exceeded when CDM and CMB was applied to sand in experiment 2. However, nutrient loading rates are more accurate than nutrient concentrations for determination of eutrophication in fresh water bodies (Schnoor and Zehnder 1996). Although concentrations of P in experiment 2 from the sand exceed the threshold concentration for P, more research needs to be conducted to determine if nutrient loading rates of total P from CMB and CDM grown sod surpass regulatory limits for loading levels of total P.

Nitrogen

Managing a healthy turfgrass requires additions of inorganic N sources. Rates recommended for St. Augustinegrass range from 146 to 292 kg ha^{-1} yr^{-1} to maintain acceptable turf quality (Turgeon 1999). Though NO_3-N concentration (7 mg kg^{-1}) is low compared to total N (6240 mg kg^{-1}) in CDM at application, mineralization could release additional NO_3-N over time. This was evident in the first study. Nitrate-N leaching from the highest manure rate measured as NO_3-N concentrations in leachate differed from the lesser rates for the third leaching event only. Though NO_3-N concentrations in leachate were greater in leaching event 1, large random variation prevented statistical significance. In addition, variation among leachate volumes collected created substantial variation in NO_3-N concentration, indicating that mass loss of NO_3-N may be more accurate to estimate leaching losses.

Rate effects on NO_3-N concentrations in leachate were observed in all leaching events when the large, volume-based rates were used. Nitrate-N concentrations collected from columns receiving CMB at the highest rate were greater than NO_3-N concentrations from CDM applications in the sand and clay soils. Total N applied using CMB at the highest rate was 2,649 kg ha^{-1} compared to 1,595 kg kg^{-1} applied as CDM. Nitrate concentrations in leachate reflected more total N was applied using CMB compared to CDM for the sand and clay soils. Both compost sources yielded values above the national drinking water standard of 10 mg NO_3-N L^{-1}. The CDM- or CMB-grown turfgrass sod could pose a threat to groundwater quality when CDM or CMB are incorporated in soil at rates up to 250 cm^{-3} L^{-1}. Easton and Petrovic (2004) found similar N concentrations in leachate after application of organic N sources during early establishment of turfgrass. Yet, after 1 yr of turfgrass growth NO_3-N and NH_4-N decreased significantly (Easton and Petrovic 2004). Applications of CDM or CMB require careful attention to the amount of synthetic N sources needed to maintain turfgrass growth to minimize environmental impacts.

Turfgrass Growth and Nutrition

Though applications of CDM or CMB can pose threats to the environment, these applications could improve turfgrass growth and quality. The growth rate response of St. Augustinegrass to CDM applications in the first study was attributed to mineralization of nutrients from CDM. Similar results were observed by Cisar (1994) and Barker (2001) in studies assessing CMB products for turfgrass growth and nutrition. Both studies indicated better growth with higher amounts of compost amendments (Cisar, 1994 and Barker, 2001).

Microbial Components

Applications of CDM or CMB may enhance microbial populations and community function. The high microbial populations during turfgrass establishment, regardless of amendment application, indicated that sufficient C was available without CDM or CMB to sustain microbial activity in a turfgrass system. Turfgrass species have a large intricate web of roots that are constantly sloughing cortical cells and exuding C-based compounds into the rhizosphere (Bigelow et al., 2002). The C-based compounds, in turn, feed the microbial population surrounding the roots. In an experiment conducted using sand-based putting greens a similar trend was observed (Bigelow et al., 2002). Microbial activity was unresponsive to rootzone amendments but was correlated to turfgrass root growth (Bigelow et al., 2002). Applications of biosolids at rates up to 250 cm^3 L^{-1}, do not add enough C to alter microbial populations under St. Augustinegrass turf.

A shift in community function occurred in experiment 1. Similar results were observed by Larkin et al. (2002), which resulted in greater N immobilization and lower plant available N when soils were amended with manure. In contrast to the responses of community function in Experiment 1, a community shift did not occur in Experiment 2. However, better plant growth was observed when CDM was applied in Experiment 1. In

Experiment 2 plant growth was unaffected by CDM or CMB applications indicating plant growth may have the greatest effect on soil microbiological communities.

CONCLUSIONS

Turfgrass sod grown with manure applied at P-based rates no greater than 400 kg total P ha^{-1} posed little threat to groundwater quality. Alternatively, turfgrass sod established using organic amendments incorporated at volume-based rates greatly increases the potential for leaching losses of P and N from sandy soils. Yet, more research needs to be conducted to determine if leachate losses of P and N are problematic for urban watersheds.

Applications of CDM and CMB during turfgrass establishment can reduce or eliminate the need for inorganic P and K applications. Though supplemental N applications are needed to maintain healthy turf, applications of inorganic N fertilizers can be reduced as well. Soil physical properties were not enhanced by CDM or CMB applications. Turfgrass established with composted manure, at P-based rates up to 400 kg manure P ha^{-1} can serve as a sink for accumulating animal or municipal waste without compromising environmental quality.

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APPENDIX A

FIGURES

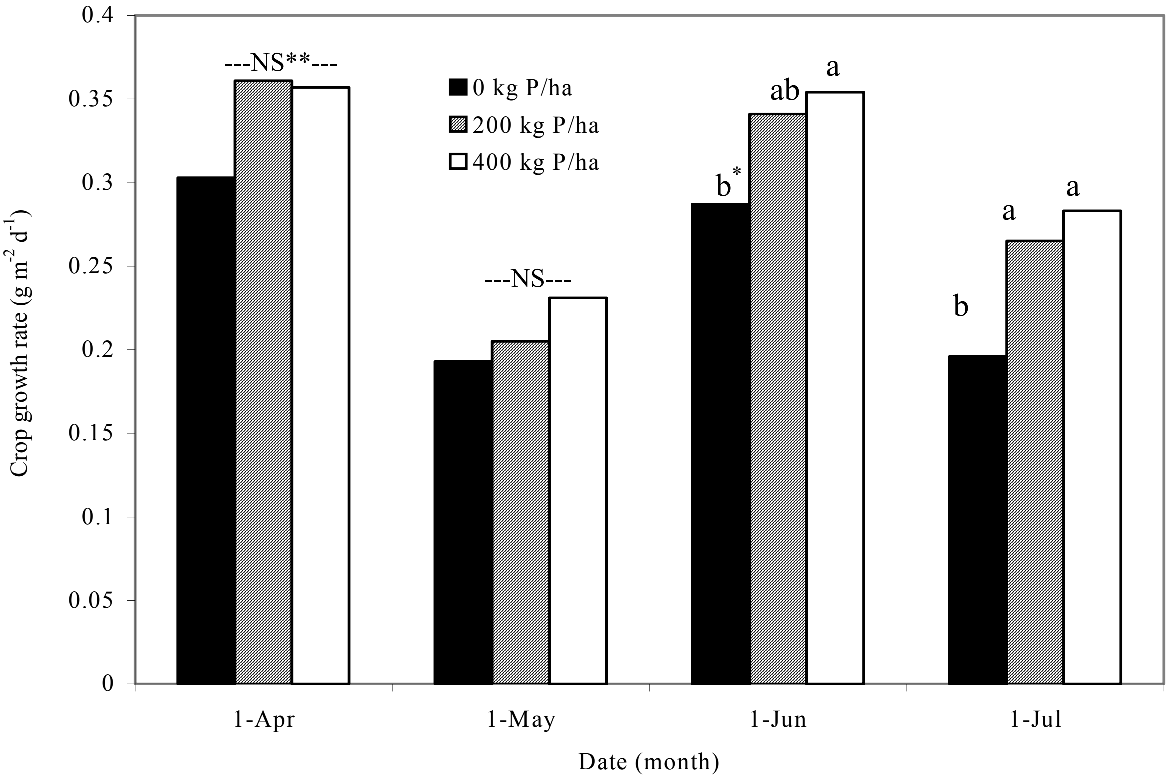

Fig. 1. Crop growth rate (g m^{-2} d^{-1}) for St. Augustinegrass as affected by composted dairy manure rate. Clipping started April 4 and ended July 4. Harvests were taken every seven days for a total of 11 harvests. The rest of the dates are missing to save space. Treatments consisted of P application rates of 0 kg ha^{-1}, 200 kg ha^{-1}, and 400 kg ha^{-1} in composted dairy manure.

[*] Treatments with the same lower case letter within dates are not significantly different at P=0.05 level using Fisher's LSD

[**] NS-not significant.

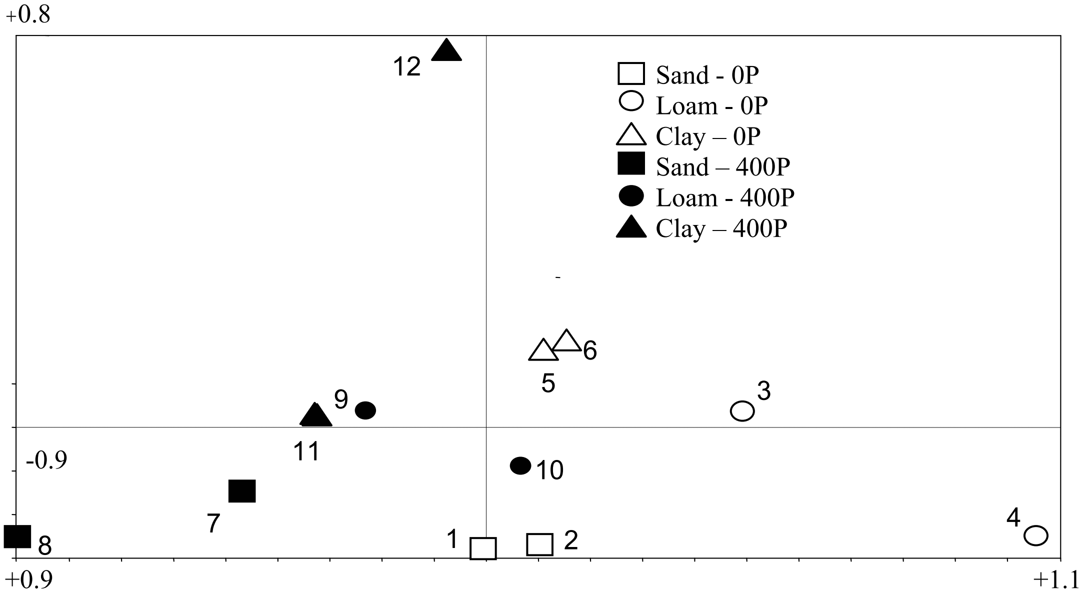

Fig. 2. Principal component analysis of carbon-source utilization by microbial communities in sand, loam, and clay treated with 0 and 400 kg P ha^{-1} as CDM.

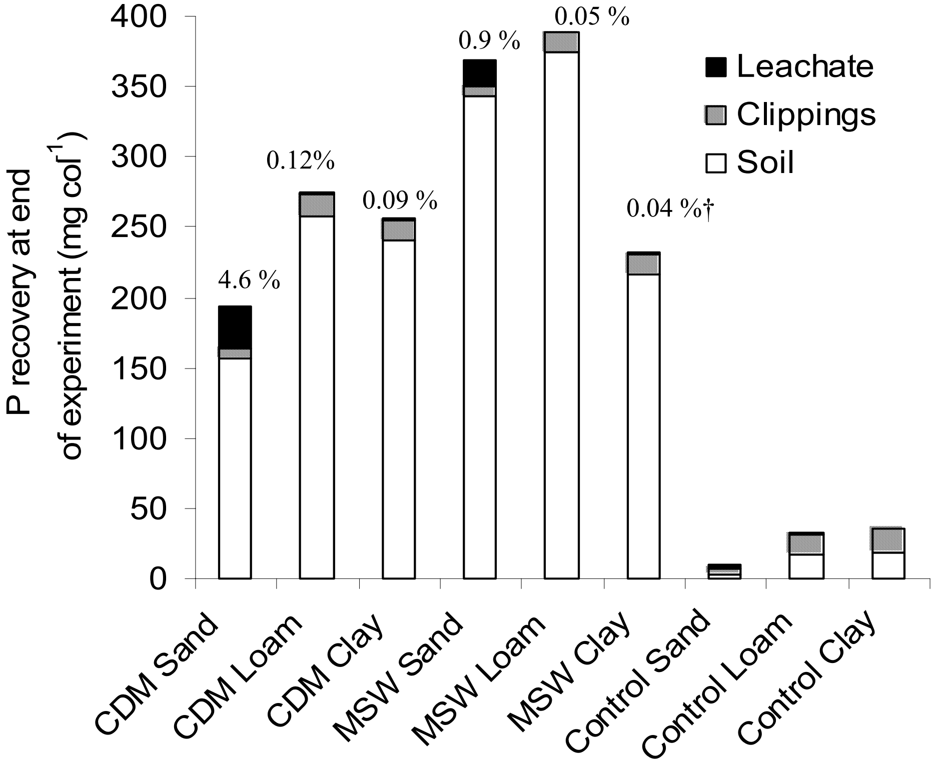

Fig. 3. Phosphorus recovery in clippings, top 12 cm of soil, and leachate for the 250 cm^3 L^{-1} rate and control during Experiment 2. Treatments consist of three soils (sand, loam, and clay) and two compost sources (CDM and CMB) incorporated to a 10 cm depth.

† Values represent percent of total P applied that was lost in leachate.

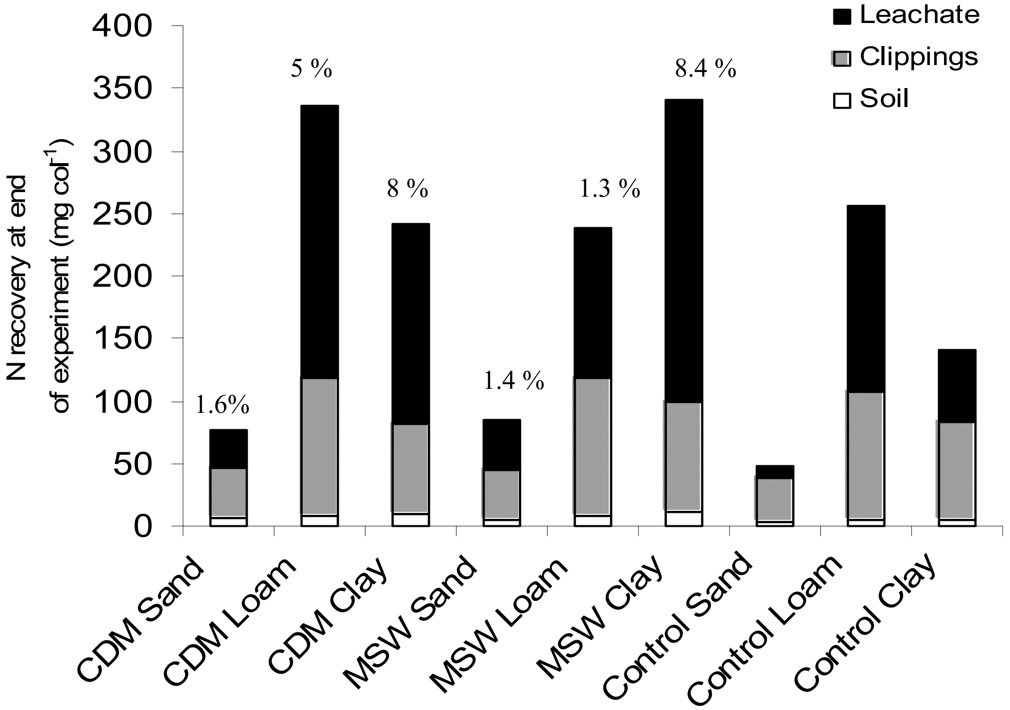

Fig. 4. Nitrogen recovery in clippings (TKN), top 12 cm soil (NO_3-N), and leachate (NO_3-N) for the 250 cm^3 L^{-1} rate and control during Experiment 2. Treatments consist of three soils (sand, loam, and clay) and two compost sources (CDM and CMB) incorporated to a 10 cm depth.

† Values represent percent of N applied that was lost in leachate, control values were subtracted from treatment values.

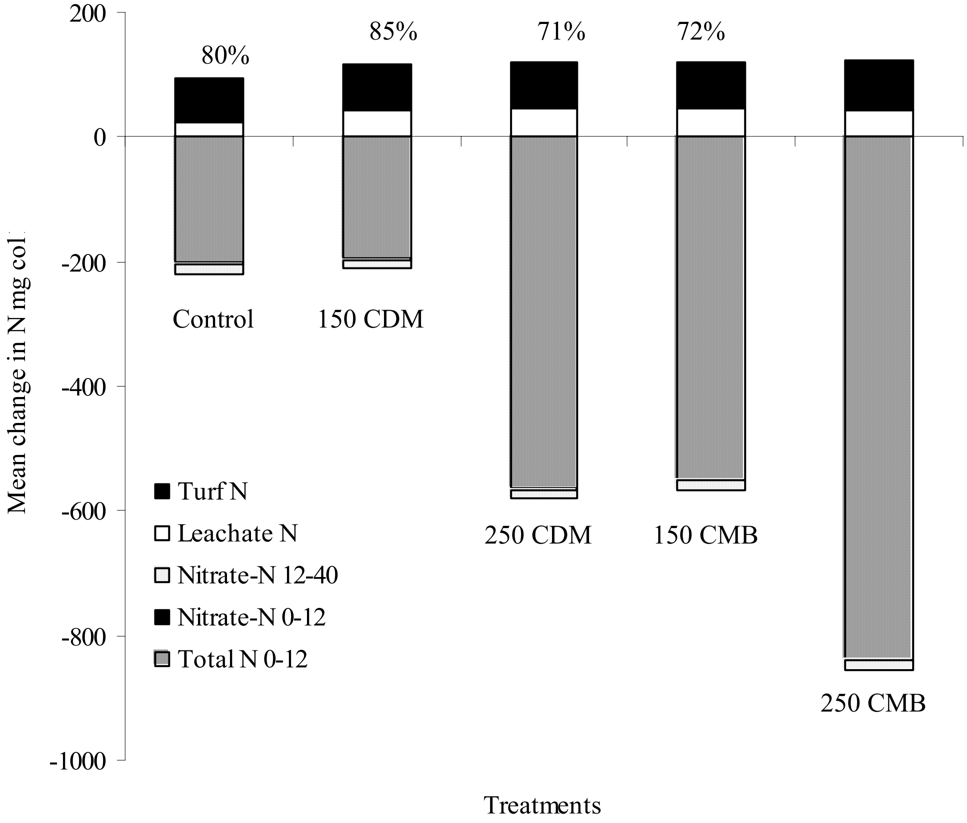

Fig. 5. Mean change in N per column for Experiment 2. Values above bars represent percent of nutrient additions collected at the end of the experiment. Treatments consist of three soils (sand, loam, and clay) and two compost sources (CDM and CMB) incorporated to a 10 cm depth.

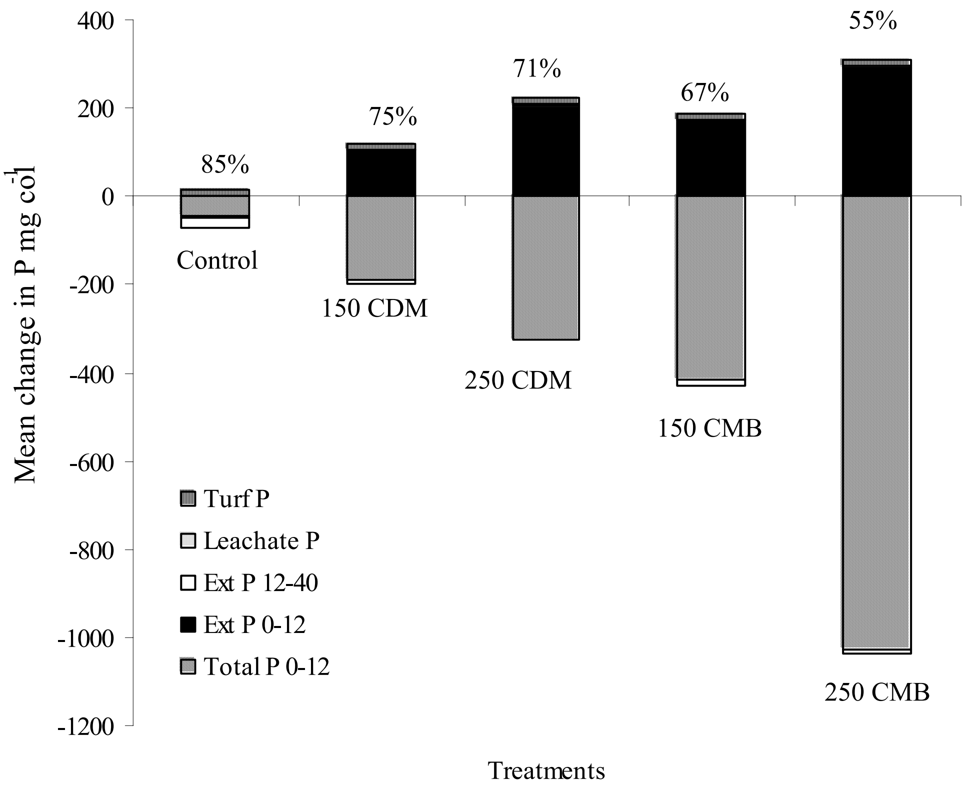

Fig. 6. Mean change in P per column for Experiment 2. Values above bars represent percent of nutrient additions collected at the end of the experiment. Treatments consist of three soils (sand, loam, and clay) and two compost sources (CDM and CMB) incorporated to a 10 cm depth.

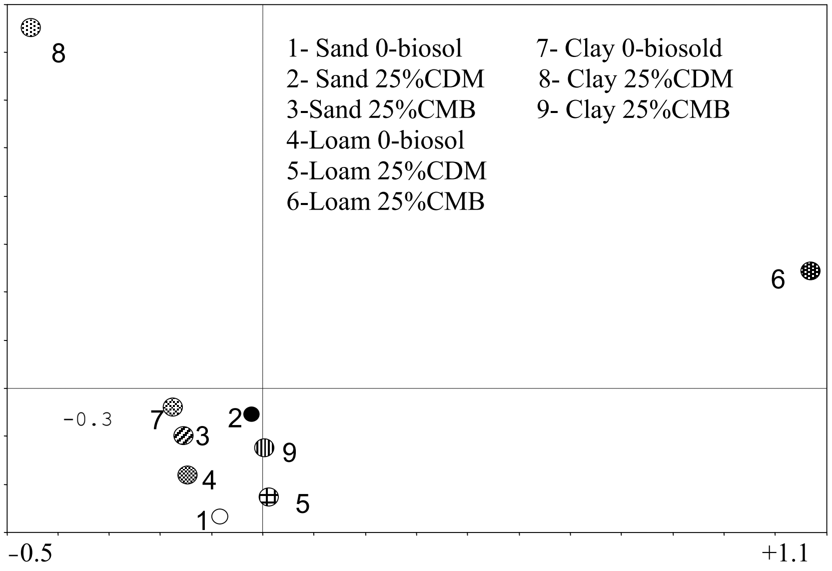

Fig. 7. Principal component analysis of carbon-source utilization by microbial communities in sand, loam, and clay treated with 0 and 250 cm^3 L^{-1} as CDM and CMB.

APPENDIX B

TABLES

Table 1. Organic matter content of the top 10cm treatment layer as affected by soil type and composted dairy manure rate in Experiment 1. Treatments consist of three soils (sand, loam, and clay) to which three rates of CDM (0, 200, and 400 kg P ha^{-1}) were applied. Samples were taken at the end of the experiment.

	Manure Rate (kg P ha^{-1})		
	0	200	400
Soil Type	Organic Matter Content (g kg^{-1})		
Sand	4c*	6b	9a
Loam	21c	25b	28a
Clay	114c	115b	116a

* Treatments with same lower case letter within rows are not statistically different at P=0.05 using Fisher's LSD.

Table 2. Responses of bulk density, gravimetric water content, and water infiltration rate among three different soil types (sand, loam, and clay) calculated from two different experiments. Experiment 1 treatments consisted of three rates (0, 200, and 400 kg total P ha^{-1}) of CDM applied to soil types mentioned above. Experiment 2 treatment consisted of two compost sources (CDM and CMB) applied at three rates (0, 150, and 250 cm^3 L^{-1}) to the soils mentioned above. Samples were collected after third leaching event.

	Bulk Density ($g\ cm^{-3}$)	Gravimetric water content ($kg\ kg^{-1}$)†	Infiltration rate ($cm\ hr^{-1}$)
Experiment 1			
Sand	1.4 a*	0.1 c	248 a
Loam	1.3 a	0.2 b	103 b
Clay	0.9 b	0.3 a	35 c
Experiment 2			
Sand	1.5 a	0.1 c	150 a
Loam	1.4 b	0.2 b	7.5b
Clay	1.1 c	0.4 a	0.4 c

* Treatments with same lower case letter within columns are not statistically different at P=0.05 using Fisher's LSD.

† At field capacity

Table 3. The nutrient (N and P) additions per lysimeter in compost applications for Experiment 1 and 2. Compost during Experiment 1 was applied at 200 and 400 kg manure P ha^{-1}(200P and 400P). Compost during Experiment 2 was applied at 150 and 250 cm^3 L^{-1}(150 and 250). Two compost sources, composted dairy manure (CDM) and composted municipal biosolid (CMB) were used in Experiment 2.

Compost Nutrient Additions (mg col^{-1})					
Exp. 1	Total N	NO_3-N	Total P	Extractable P	NO_3-N Fert
CDM 200P	285	0.32	158	81	39
CDM 400P	570	0.64	317	163	112
Exp. 2	Total N	NO_3-N	Total P	Extractable P	NO_3-N Fert
CDM 150	620	0.8	341	173	39
CDM 250	1264	1.6	696	353	39
CMB 150	981	1.3	913	59	39
CMB 250	2084	3	1941	124	39

Table 4. Extractable P concentrations for St. Augustinegrass columns in the top 10cm of soil (treatment layer) as affected by composted dairy manure rate and soil type in Experiment 1. Treatments consist of three soils (sand, loam, and clay) to which three rates of CDM (0, 200, and 400 kg P ha^{-1}) were applied.

	Manure Rate (kg P ha^{-1})		
	0	200	400
Soil Type	Extractable P concentration (mg kg^{-1})		
Sand	2.1 c[*]	53.8 b	109.5 a
Loam	7.3 c	60.8 b	123.5 a
Clay	40.1 c	105.3 b	167.9 a

[*] Treatments with same lower case letter within rows are not statistically different at P=0.05 using Fisher's LSD.

Table 5. Water extractable phosphorus in the top 10cm of soil for St. Augustinegrass columns (treatment layer) as affected by composted dairy manure rate and soil type. Treatments consist of three soils (sand, loam, and clay) to which three rates of CDM (0, 200, and 400 kg P ha^{-1}) were applied.

	Manure Rate (kg P ha^{-1})		
	0	200	400
Soil Type	Water Extractable P (mg kg^{-1})		
Sand	0.3c*	0.8b	1.2a
Loam	0.9c	1.5b	2.2a
Clay	1.0c	1.2b	1.8a

* Treatments with same lower case letter within rows are not statistically different at P=0.05 using Fisher's LSD.

Table 6. Leachate concentrations of NO_3-N collected from column lysimeters of St. Augustinegrass. Treatments consisted of three soil types (sand, loam, and clay) to which three rates (0, 200, 400 kg total P ha^{-1}) of CDM were applied and incorporated to a 10-cm depth.

	Leaching Event								
	1			2			3		
	N Rate (kg ha^{-1})								
	50	363	726	50	363	726	50	363	726
Soil	NO_3-N concentration (mg L^{-1})								
Sand	2.2a	1.8a	1.2a	4.4a	4.6a	6.1a	6.1b	9.3a	8.6a
Loam	149.6a	0.1a	0.2a	6.4a	12.9a	4.3a	2.1b	41.6a	10.4a
Clay	75.9a	109.3a	124.4a	4.2a	3.5a	18.8a	0.1b	0.6a	0.3a

† NO_3-N concentrations with the same lower case letter within a row for each leaching event are not statistically different at P=0.05 using Fisher's LSD.

Table 7. Leachate loss of NO_3-N collected from column lysimeters of St. Augustinegrass. Treatments consisted of three soil types (sand, loam, and clay) to which three rates (0, 200, 400 kg total P ha^{-1}) of CDM were applied and incorporated to a 10-cm depth.

	Leaching Event									
	1			2			3			
	N Rate (kg ha^{-1})									
Soil	50	363	726	50	363	726	50	363	726	Mean
	NO_3-N loss (mg)									
Sand	1.3a†	1.1a	0.7a	0.4a	0.1a	0.2a	0.1a	0.1a	0.0a	0.4C*
Loam	30a	0.1a	0.1a	1.9a	3.6a	0.7a	0.9a	10.8a	2.6a	5.3B
Clay	58.6a	46.6a	31.9a	1.4a	1.3a	3.3a	0.1a	0.3a	0.1a	15A

† NO_3-N losses with the same lower case letter within a row for each leaching event are not statistically different at P=0.05 using Fisher's LSD.

*Mean NO_3-N loss of soil types followed by the same capital letter are not significantly (P=0.05) different

Table 8. Leachate concentration of P collected from column lysimeters of St. Augustinegrass. Treatments consisted of three soil types (sand, loam, and clay) to which three rates (0, 200, 400 kg total P ha^{-1}) of CDM were applied and incorporated to a 10-cm depth.

	Leaching Event									
	1			2			3			
	P rate (kg ha^{-1})									
Soil	0	200	400	0	200	400	0	200	400	Mean
	P concentration (mg L^{-1})									
Sand	1.1a†	1.2a	1.2a	0.4a	0.6a	0.4a	0.6a	2.3a	0.9a	0.9A*
Loam	1.3a	1.1a	0.9a	0.3a	0.1a	0.2a	0.3a	0.2a	0.2a	0.5B
Clay	1.1a	1.5a	1.2a	0.1a	0.2a	0.2a	0.2a	0.2a	0.2a	0.5B

† P rates with the same lower case letter within a row for each leaching event are not statistically different at P=0.05 using Fisher's LSD.

*Mean P concentrations of soil types followed by the same capital letter are not significantly (P=0.05) different.

Table 9. Leachate loss of P collected from column lysimeters of St. Augustinegrass. Treatments consisted of three soil types (sand, loam, and clay) to which three rates (0, 200, 400 kg total P ha^{-1}) of CDM were applied and incorporated to a 10-cm depth.

	Leaching Event									
	1			2			3			
	P rate (kg ha^{-1})									
Soil	0	200	400	0	200	400	0	200	400	Mean
	P loss (mg)									
Sand	0.7a†	0.7a	0.7a	0.2a	0.3a	0.1a	0.2a	1.1a	0.3a	0.5A*
Loam	0.5a	0.7a	0.4a	0.1a	0.0a	0.0a	0.1a	0.1a	0.0a	0.2B
Clay	0.8a	0.8a	0.3a	0.1a	0.1a	0.0a	0.0a	0.1a	0.0a	0.2B

† P rates with the same lower case letter within a row for each leaching event are not statistically different at P=0.05 using Fisher's LSD.

*Mean P loss of soil types followed by the same capital letter are not significantly (P=0.05) different.

Table 10. Bulk density values calculated at the start of experiment 2. Treatment consisted of three soils (sand, loam, and clay), two compost sources (CDM and CMB), and two rates (150 and 250 $cm^3\ L^{-1}$).

	Composted Dairy Manure ($cm^3\ L^{-1}$)			Composted Municipal Biosolids ($cm^3\ L^{-1}$)		
	0	150	250	0	150	250
	Bulk Density ($g\ cm^{-3}$)					
Soil						
Sand	1.4 a	1.4 a	1.5 a	1.4 a	1.4 b	1.4 b
Loam	1.4 a	1.4 a	1.4 a	1.4 a	1.3 b	1.3 b
Clay	1.3 a	1.3 a	1.2 a	1.3 a	1.2 b	1.2 b

†Treatment with the same letter within a row and compost column are not statistically different at P=0.05 using Fisher’s LSD.

Table 11. Organic matter content of the top 12 cm layer of soil as affected by compost amendment rate and type. Treatments comprised combinations of three soil types (sand, loam, and clay), two compost sources (CDM and CMB), and three rates (0, 150, 250 cm^3 L^{-1}).

	Composted Dairy Manure (cm^3 L^{-1})			Composted Municipal Biosolid (cm^3 L^{-1})		
	0	150	250	0	150	250
Soil	Organic Matter (g kg^{-1})					
Sand	3.5c[*]	13b	14.3a	3.5c	9.5b	34a
Loam	30.7c	41.0b	46.2a	30.7c	48.7b	82.0a
Clay	200a	107a	105a	200a	152a	145a

[*] Treatments with same lower case letter within a row for each compost source are not significantly different at P=0.05 using Fisher's LSD.

Table 12. Initial and final total N and P content of the surface layer. Treatment consist of three soils (sand, loam, and clay), two compost sources (CDM and CMB), and two application rates (150 and 250 cm^3 L^{-1}).

Start	Total N (mg col^{-1})					Total P (mg col^{-1})				
Exp.2	0	150 CDM	250 CDM	150 CMB	250 CMB	0	150 CDM	250 CDM	150 CMB	250 CMB
Sand	368	688	1332	1049	2152	88	390	745	962	1990
Loam	982	1202	1846	1563	2666	127	468	823	1040	2068
Clay	1488	1708	2352	2069	3172	436	677	1032	1249	2277

End	Total N (mg col^{-1})					Total P (mg col^{-1})				
Exp.2	0	150 CDM	250 CDM	150 CMB	250 CMB	0	150 CDM	250 CDM	150 CMB	250 CMB
Sand	247c*	520 b	790a	703b	1106a	70c	94b	271aB	389b	666a
Loam	705c	904b	1163a	1218b	1612a	84c	266b	355aB	472b	926a
Clay	1341c	1588b	1881a	2011b	2752a	368cC	601b	999a	1144b	1652a

Units for rates are cm^3 L^{-1}.

*Treatments with same lower case letter are not significantly different at P=0.05 using Fishers LSD with regard to rate effects.

Table 13. Extractable NO_3-N concentrations in the top 12 cm of soil (treatment layer) as affected by compost source and rate and soil type in Experiment 2. Treatments consist of three soils (sand, loam, and clay) to which three rates of CDM and CMB (0, 150, and 250 $cm^3 L^{-1}$) were applied.

	Composted Dairy Manure ($cm^3 L^{-1}$)			Composted Municipal Biosolid ($cm^3 L^{-1}$)		
	0	150	250	0	150	250
	---NO_3-N concentration (mg kg^{-1})---					
Sand	2.0 c*	2.9 b	3.3 a	2.0 c	2.8 b	3.7 a
Loam	3.7 c	4.5 b	7.3 a	3.7 c	5.0 b	6.2 a
Clay	4.2 c	6.3 b	8.5 a	4.2 c	8.2 b	10.2 a

* Treatments with same lower case letter within rows for each compost source are not statistically different at P=0.05 using Fisher's LSD.

Table 14. Extractable soil P concentrations with depth affected by compost source and rate and soil type. Treatments comprise combinations of three soil types (sand, loam, and clay), two compost sources (CDM and CMB), and three rates (0, 150, and 250 $cm^3 L^{-1}$).

	Composted Dairy Manure ($cm^3 L^{-1}$)			Composted Municipal Biosolid ($cm^3 L^{-1}$)		
	0	150	250	0	150	250
Sand	P concentration (mg kg^{-1})					
12	1.6c*	62.8b	94.9a	1.6c	129.3b	208.9a
20	1.3c	3.7b	5.6a	1.3c	3.6b	4.1a
30	1.4b	3.2a	4.3a	1.4b	3.5a	3.6a
40	1.5b	3.5a	5.1a	1.5b	3.4a	3.6a
Loam						
12	14.4c	104.9b	214.6a	14.4c	198.6b	312.4a
20	12.5c	25.9b	40.9a	12.5c	18.7b	36.7a
30	12.1a	12.8a	15.8a	12.1a	12.2a	13.9a
40	11.3a	12.1a	12.3a	11.3a	12.0a	12.9a
Clay						
12	17.2c	124b	219a	17.2c	112b	196a
20	14.3c	17.1b	28.7a	14.3c	23.3b	27.6a
30	13.6a	23.3a	27.6a	13.6a	14.7a	15.3a
40	14.5a	14.8a	14.1a	14.5a	14.0a	14.0a

* Treatments with same lower case letter within a row for each compost source are not significantly different at P=0.05 using Fisher's LSD.

Table 15. Water extractable P concentration of 0 to 12-cm layer as affected by amendment type and rate. Treatments comprised combinations of three soil types (sand, loam, and clay) two amendment sources (CDM and CMB) and three rates (0, 150, 250 cm^3 L^{-1}).

	Composted Dairy Manure (cm^3 L^{-1})			Composted Municipal Biosolid (cm^3 L^{-1})			
	0	150	250	0	150	250	Mean
Soil	Water Extractable P (mg kg^{-1})						
Sand	0.9b[*]	1.2a	1.2a	0.9b	0.8b	1.2a	1.1A†
Loam	0.8b	1.4a	1.5a	0.8b	1.2a	1.9a	1.4A
Clay	0.5b	0.9a	1.8a	0.5b	1.4a	1.5a	1.2A

[*] Treatments with same lower case letter within a row for each compost source are not significantly different at P=0.05 using Fisher's LSD.

†Water extractable P values of soil types followed by the same capital letter are not significantly (P=0.05) different within the column of mean soil values.

Table 16. The NO_3-N leachate concentration collected after applications of one pore volume of distilled water for three leaching events. Treatments consist of three soils (sand, loam, and clay) to which CDM and CMB were incorporated within the 0 to 10-cm depth at rates of 0, 150, and 250 $cm^3 L^{-1}$.

	Composted Dairy Manure ($cm^3 L^{-1}$)			Composted Municipal Biosold ($cm^3 L^{-1}$)		
	0	150	250	0	150	250
Sand	--- -- --- --- --- --- --- --- ---NO_3-N concentration(mg L^{-1})--- --- --- --- ---					
Leach 1	13.7a[*]	29.5a	8.8a	13.7b	12.8b	17a
Leach 2	3.8c	5.0b	8.8a	3.8c	6.8b	16.5a
Leach 3	0.6b	1.4a	2.8a	0.6b	2.9a	2.7a
Loam						
Leach 1	21.5c	59.3b	158.3a	21.5c	29.5b	74.5a
Leach 2	84a	43a	84a	84a	82a	65a
Leach 3	28.6a	45.2a	13.9a	28.6a	34.2a	6.8a
Clay						
Leach 1	242a	259a	187a	242a	226a	280a
Leach 2	16.8a	19.3a	32.5a	16.7a	16.3a	18.5a
Leach 3	0.8b	4.1a	3.4a	0.8b	5.2a	7.5a

[*] Treatments with same lower case letter within a row and compost column are not significantly different at the 0.05 level using Fisher's LSD (P=0.05).

Table 17. The NO_3-N loss in leachate collected after applications of one pore volume of distilled water for three leaching events. Treatments consist of three soils (sand, loam, and clay) to which CDM and CMB were incorporated within the 0 to 10-cm depth at rates of 0, 150, and 250 $cm^3 L^{-1}$.

	Composted Dairy Manure ($cm^3 L^{-1}$)			Composted Municipal Biosolid ($cm^3 L^{-1}$)		
	0	150	250	0	150	250
Sand	NO_3-N loss (mg col^{-1})					
Leach 1	2.9b*	10.2a	29.8a	2.9b	13.7a	17.9a
Leach 2	3.3a	5.69a	8.3a	3.3a	7.8a	19.5a
Leach 3	2.8a	1.6a	2.9a	2.8a	2.9a	2.9a
Loam						
Leach 1	24.9b	55.3a	88.8a	24.9b	29.4a	46.2a
Leach 2	99a	53.1a	116a	99a	95.6a	68.3a
Leach 3	25.3a	24.8a	12.2a	25.2a	16.9a	4.09a
Clay						
Leach 1	46.6b	216.5a	141.1a	46.6b	224a	223a
Leach 2	11.4a	20.4a	17.0a	11.4a	19.1a	9.7a
Leach 3	0.5a	5.3a	2.0a	0.5a	4.3a	8.8a

* Treatments with same lower case letter within a row and compost source are not significantly different at P=0.05 using Fisher's LSD (P=0.05).

Table 18. The P leaching loss in one pore volume of distilled water applied during three leaching events. Treatments consist three soils (sand, loam, and clay) to which CDM and CMB were applied at rates of 0, 150, and 250 $cm^3 L^{-1}$.

	Composted Dairy Manure ($cm^3 L^{-1}$)			Composted Municipal Biosolid ($cm^3 L^{-1}$)		
	0	150	250	0	150	250
Sand	P loss (mg col^{-1})					
Leach 1	1.5b*	15.9a	18.2a	1.5b	9.7a	10.9a
Leach 2	0.6b	6.7a	6.8a	0.6b	5.9a	4.4a
Leach 3	0.2b	2.3a	4.4a	0.2b	2.5a	2.7a
Loam						
Leach 1	0.6a	0.3a	0.3a	0.6a	0.5a	0.6a
Leach 2	0.4a	0.3a	0.4a	0.4a	0.4a	0.3a
Leach 3	0.13a	0.2a	0.2a	0.1a	0.1a	0.1a
Clay						
Leach 1	0.1a	0.3a	0.3a	0.1a	0.4a	0.3a
Leach 2	0.4a	0.4a	0.3a	0.4a	0.4a	0.3a
Leach 3	0.4a	0.3a	0.1a	0.4a	0.2a	0.2a

* Treatments with same lower case letter within a row are not significantly different at P=0.05 using Fisher's LSD.

Table 19. The P concentration in leachate in one pore volume of distilled water applied during three leaching events. Treatments consisted of three soils (sand, loam, and clay) to which CDM and CMB were applied at rates of 0, 150, and 250 cm^3 L^{-1}.

	Composted Dairy Manure (cm^3 L^{-1})			Composted Municipal Biosolid (cm^3 L^{-1})		
	0	150	250	0	150	250
Sand	P concentration (mg L^{-1})					
Leach 1	1.4b*	10.9a	15.7a	1.4b	8.7 a	10.2a
Leach 2	0.6 b	5.9a	7.9a	0.7b	5.0a	4.0.a
Leach 3	0.2 b	2.0a	4.2 a	0.2b	2.4a	2.6 a
Loam						
Leach 1	0.5 a	0.3a	0.3a	0.5a	0.5a	0.6a
Leach 2	0.4 a	0.4a	0.6a	0.4a	1.5a	0.4a
Leach 3	0.3 a	0.2a	0.3a	0.3a	0.2a	0.2a
Clay						
Leach 1	0.5a	0.4a	0.7a	0.5a	0.4a	0.4a
Leach 2	0.5a	0.4a	0.6a	0.5a	0.3a	0.4a
Leach 3	1.0 a	0.6a	0.5a	1.0a	0.3a	0.8a

* Treatments with same lower case letter within a row for each compost source are not significantly different at P=0.05 using Fisher's LSD.

Table 20. Molybdate reactive P loss in leachate collected after one pore volume during three leaching events. Treatments consist of three soils (sand, loam, and clay) to which CDM and CMB were applied at three rates 0, 150, 250 $cm^3 L^{-1}$.

	Composted Dairy Manure ($cm^3 L^{-1}$)			Composted Municipal Biosolid ($cm^3 L^{-1}$)		
	0	150	250	0	150	250
Sand	Molybdate Reactive P loss (mg)					
Leach 1	1.2b[*](80)[†]	10.7a (67)	12.5a (69)	1.2 b (81)	9.0 a (93)	7.4 a (68)
Leach 2	0.2b (58)	3.2a (48)	4.0a (58)	0.2b (38)	2.2a (37)	2.8a (65)
Leach 3	0.1b (55)	2.9a (87)	4.3 a (98)	0.1b (55)	2.8 a (80)	2.6a (95)
Loam						
Leach 1	0.1a (13)	0.1a (32)	0.1a (32)	0.1a (13)	0.0a (8)	0.1a (8)
Leach 2	0.1a (24)	0.1a (33)	0.1a (28)	0.1a (24)	0.1a (18)	0.1a (24)
Leach 3	0.1a (62)	0.1a (71)	0.1a (71)	0.1a (62)	0.2a (88)	0.1a (57)
Clay						
Leach 1	0.0a (20)	0.1a (31)	0.1a (28)	0.0a (20)	0.1a (27)	0.1a (30)
Leach 2	0.1a (21)	0.1a (14)	0.1a (17)	0.1a (21)	0.1a (17)	0.1a (24)
Leach 3	0.1a (35)	0.2a (69)	0.1a (63)	0.1a (35)	0.1a (74)	0.2a (80)

[*] Treatments with same lower case letter within a row for each compost source are not significantly different at P=0.05 using Fisher's LSD.

[†] Numbers in parenthesis are percentages of total dissolved P in leachate that is molybdate reactive.

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I was born in Wheaton, IL on January 30, 1980 to David and Evelyn Kerns. We left IL in 1986 and moved to Houston TX. We then left Houston, in 1989 and moved to McAllen, TX. I attended six months of high school at McAllen High School when we moved again to Sanford, NC in 1994. I graduated from Lee Senior High School in 1998 and enrolled at North Carolina State University in the fall of 1998.

Education: Texas A&M University
M.S. Agronomy
Graduation date: December 2004

North Carolina State University
B.S. Agronomy
Graduation date: May 2002

Professional Experience:

Graduate Assistant: Texas A&M University
- Thesis topic: Biosolid amendment effects on N and P leaching losses and soil properties during turfgrass establishment.
- Taught two semesters of Intro to Turfgrass Management Laboratory
- Experience with SAS, Microsoft Office, and Sigma Plot.

Student Research Assistant: North Carolina State University
- Supervised research trials on N utilization and fate
- Worked extensively with Dr. Charles Peacock on data analysis and collection
- Revised three water quality extension publications