Appendix O

Practice Verification Study Reports

The individual study manager processed and analyzed data contained in the verification study reports. Information within the report was also reviewed for accuracy by the principal investigators, project manager and project quality assurance officer.

Establishment of Newly Constructed Landscapes and Turfgrass

Effects of Dairy Manure Compost Application Timing on Coastal Bermudagrass

Effects of Dairy Manure Compost Application Rate on Coastal Bermudagrass

Using Dairy Manure Compost for Corn Silage Production

Use of Dairy Manure Compost to Establish Jose Tall Wheatgrass

Efficacy of Using Dairy Manure Compost as Erosion Control and Revegetation Material.

Use of Dairy Manure Compost as Erosion Control
Material Under Vegetated and Non Vegetated Conditions

Urban Uses for Composted Dairy Manure

John J. Sloan, Cynthia McKenney, Wayne Mackay, and Steve George
Texas A&M University Research and Extension Center at Dallas

BACKGROUND

Construction of new homes and businesses is a continuous process in rapidly growing urban areas such as the Dallas metropolis. Post-construction landscaping is usually approached from only the plant-selection viewpoint and little effort is devoted to the severely disturbed soil. Subsoil and construction debris are often mixed with or completely replace the original top soil. Although ornamental plants and turf grasses planted in these disturbed soils may perform well in the short term due to abundant watering and fertilization, they frequently decline with time when heat and drought stress become prevalent. Dairy manure compost (DMC) is a readily available soil organic matter amendment in many areas due to the presence of large dairy operations. These dairy operations need alternative ways to dispose of their manure because soils surrounding the diary operations are often elevated in soil P. Consequently, dairy farmers and state regulatory agencies are considering urban markets for composted dairy manure.

OBJECTIVES

The objective of this study was to evaluate the effect of large single applications of DMC on the establishment and subsequent growth of typical urban landscape plants and to evaluate the effects on soil chemical and physical properties.

PROCEDURE

Experimental plots measuring 6x6 m were established on a fallow agricultural field. Dairy manure compost purchased from Erath Earth Compost, Dublin Texas was applied at rates of 0, 9, 18, and 27 kg m^{-2} and incorporated into the soil using a field cultivator. Selected chemical and physical properties of the compost are shown in Table 1. Compost applications supplied large amounts of N, P, and K to the soil (Table 2). Following the application and incorporation of compost, half of each plot was established with bermudagrass sod and the other half was established with 9 different ornamental plants consisting of annual, perennial, and woody species (Fig. 1). Plant performance data was collected for three summers. Soil samples were collected each summer for nutrient analysis. Soil compaction was measured using a hand-held penetrometer and infiltration rate was measured with a Guelph infiltrometer.

RESULTS

Soil properties

Infiltration Rate and soil moisture: Water infiltration into the Austin silty clay soil was significantly increased by application of dairy manure composts 18 months after application (Fig. 2). Consequently, rainfall and irrigation water infiltrated the compost-amended plots more quickly reducing the possibility of loss due to runoff or evaporation. This suggests that soil moisture levels following rainfall or irrigation would be elevated in the compost-amended plots, especially in the subsoil where water was able to infiltrate more easily.

Soil moisture measurements during the first two growing seasons verified that soil moisture in the surface (0-7.5 cm) and subsurface (7.5-15 cm) were elevated in compost-amended plots (Fig. 3). Soil moisture was measured twice during the first growing season after application of the dairy manure compost and once during the second growing season. Soil moisture was measured at depths of 0-7.5 cm (0-3 inches) and 7.5-15 cm (3 to 6 inches). Soil moisture was seldom limiting during either growing season because plots were irrigated weekly with 2.5 to 5 cm water (1 to 2 inches). Soil moisture at both depths consistently increased with increasing rates of dairy manure compost for both irrigated growing seasons, but the relationship was not always statistically significant due to a large degree of variability in the data (Fig. 3). In contrast, during the 2005 growing season, turf plots were not irrigated so that we could observe the effect of compost amendments under natural rainfall conditions. Under conditions of no irrigation, soil moisture decreased with compost application rate (July 24, 2005). This decrease in soil moisture in the absence of irrigation can be attributed to greater transpiration by the healthier, more vigorous turfgrass growing on the compost plots.

Soil compaction: Addition of organic matter to soil may have the positive benefit of reducing soil compaction and soil resistance to penetration. To evaluate this possibility, soil resistance to penetration was measured in 5 cm increments to a depth of 45 cm using a hand-held cone penetrometer (Spectrum Technologies). Soil resistance measurements in the upper 20 cm were significantly reduced with the addition of dairy manure compost—especially with the highest rate of 27 kg m^{-2} (Fig. 4) Below 20 cm, there appeared to be a trend towards reduced soil resistance in the compost-amended plots, but the effect was not statistically significant. Reduced penetration resistance in soil can increase root length by making it easier for roots to expand into the soil (Bradford, 1980). Soil resistance is influenced by soil moisture, especially in clay soils like those in these study plots (Lowery and Morrison, 2002). Soil moisture was not measured at the same time the penetrometer measurements were collected, but data collected at other times showed that compost application increased water infiltration rate (Fig 2) and water content in the upper 15 cm of the soil (Fig. 3). It is likely that increased subsoil water content in the compost-amended plots reduced soil resistance measurements collected with the penetrometer.

Soil Phosphorus: Dairy manure compost contains high concentrations of plant nutrients (Table 1), so large application rates will result in a significant input of nutrients to the soil (Table 2). Phosphorus is the primary nutrient of concern because excessive soil P can potentially reduce surface water quality when soluble and particulate forms of P reach surface water bodies.

Soluble P was measured two times during the first growing season after application of the dairy manure compost. At both dates, dairy manure compost significantly increased soluble P in the upper 7.5 cm of the soil, but there was no effect at deeper depths (Fig. 5). This suggests that the compost was mostly incorporated into the upper 7.5 cm of the soil. Soluble P numbers in the upper 7.5 cm were higher for the second sampling date, suggesting that there was considerable mineralization of the dairy manure compost between the first and second date.

Plant available P was measured along with other soil nutrients at the end of the second growing season. Composite soil samples were extracted from the 0-7.5, 7.5-15, and 15-22.5 cm depths and sent to the Texas Cooperative Extension Soil, Water, and Forage Testing Laboratory in College Station, Texas for a routine soil fertility analysis. Dairy manure compost significantly increased Mehlich 3 extractable plant available P at the 0 to 7.5 cm depth and also the 7.5 to 15 cm depth (Table 3). Plant available P ranged from 89 to 170 mg kg^{-1} in the upper 7.5 cm of compost-amended soil, and from 34 to 64 mg kg^{-1} in the 7.5 to 15 cm depth. Plant available P in the upper 7.5 cm of compost-amended plots exceeded the critical P level of 45 mg kg^{-1}, demonstrating that even modest applications of dairy manure compost can supply adequate P. Large DMC applications ($\leq$27 kg m^{-2}) may actually add excessive P to the soil. Consequently, large repeated applications of DMC should be avoided because they can elevate soil P to levels that increase the risk of surface water quality degradation. Dairy manure compost had no effect on plant available P at the 15 to 22.5 cm depth (data not shown).

Soil fertility: Dairy manure compost was an excellent source of essential plant macro- and micro-nutrients. Plant available K, S, Fe, Zn, and Cu in the upper 15 cm of soil were all increased by DMC applications (Table 3). Dairy manure compost also increased soil NO_3-N, although the effect was only significant at the 7.5-15 cm depth. One of the greatest advantages of DMC is that it is a safe source of nearly all the essential plant nutrients. In the calcareous clay soils typical of the Blacklands Resource area, certain plant nutrients, such as Fe, Zn, and Cu are frequently limiting.

The soil samples represented in Table 3 were collected at the end of the second growing season following DMC application to this Austin silty clay soil, and at that time, there was still a greater concentration of essential plant nutrients in the DMC-amended soils. Continued availability of essential plant nutrients in compost-amended soils is one of the reasons it makes sense to use a large application of compost when initially establishing urban landscapes. As the compost organic matter continues to mineralize over the next few growing seasons, there will continue to be an elevated concentration of plant available nutrients in the compost-amended soils. This will reduce the need for subsequent fertilization. The organic matter content of the DMC-amended soils was significantly greater than un-amended soil (Table 3), suggesting that the compost will continue to supply essential plant nutrients as the compost organic matter continues to mineralize in the soil.

Compost application rate had no significant effect on soil pH or electrolytic conductivity (EC) at the 0-7.5 cm depth, but decreased soil pH and increased EC at the 7.5-15 cm depth (data not shown). Austin silty clay soil tends to be calcareous in nature with pH values that typically range from 7.8 to 8.2. Soil amendments that decrease soil pH would be beneficial to this soil. Even though soil EC was slightly increased by compost applications at the 7.5 to 15 cm depth, the range in values (408 to 533 $\mu S\ cm^{-1}$) showed that excessive salinity was not a concern in these soils.

Ornamental Plants

Ornamental plants showed varying degrees of response to dairy manure applications based on the four plant growth indicators that were used in this study (overall rating, plant growth index, percent flowering, and chlorophyll index). Two plant species (Crape myrtle and Shasta daisy) showed no response to DMC applications for any of the plant growth indicators. Each of these indicators is discussed below. In general, the annual and perennial plants were more likely to demonstrate positive responses to dairy manure applications. Out of all the ornamental plants evaluated, Lantana was the most likely to respond to diary manure applications, followed by Pentas (Egyptian Star flower) and Dwarf Burford Holly. The was sufficient evidence in the plant growth indicators to conclude that incorporation of dairy manure compost into the soil when initially establishing an urban landscape will improve the subsequent establishment and growth of ornamental plants.

Overall rating: The overall rating of a plant is a visual rating based on the vegetative (foliage) and flowering parts of the plant. A maximum rating of 10 would be given to a plant that has optimum vegetative and flowering properties. For non-flowering plants, like the Burford Holly and Yaupon Holly, the overall rating is based only on the vegetative part of the plant. The overall rating of Burford Holly, Lantana, Penta, and Rose plants was significantly increased in the compost-amended soils (Fig. 6).

Plant growth index: The plant growth index (PGI) demonstrates how the overall size of the plant was affected by DMC applications. The PGI is based on the height and width of the plant. Burford Holly, Lantana, Penta, and Yaupon Holly all responded significantly to dairy manure applications, indicating that their growth was increased by the addition of DMC to the soil (Fig. 7).

Percent flowering: Percent flowering is a visual estimation of the percentage of the plant that is covered with flowers. Flowering in the Lantana, Penta, and Rose plants was significantly increased in the compost-amended soils (Fig. 8).

Chlorophyll rating: The chlorophyll rating was an actual measurement taken with a chlorophyll meter (SPAD-502, Spectrum Technologies, Inc, Plainfield, Illinois). The SPAD meter estimates the amount of chlorophyll in a leaf by measuring light absorbance at two wavelengths characteristic of chlorophyll. Chlorophyll measurements are directly correlated to the nutritional status of the plant, especially as it relates to nitrogen concentration. Only Echinacia (Purple coneflower) and Lantana had greater chlorophyll contents in the compost-amended soils (Fig. 9). Both these plants exhibit most of their growth in the spring and summer months, so they would be most likely to benefit from adequate nitrogen availability in the soil.

Lantana: Lantana was the ornamental plant that responded most favorably to dairy manure applications. During the winter months in North Texas, above-ground parts of Lantana plants die, which causes the leaves to drop to the ground leaving behind only dried stems (Fig. 10). When these stems were harvested and weighed, there was a strong correlation between stem weights and dairy manure compost application rate (Fig. 11). When winter conditions are not too harsh, Lantana will survive and re-grow in the spring. In the compost plots, Lantana was not well protected from the winter elements, so it tended to die during the winter months. However, visual observations in the spring showed that some Lantana plants survived in plots that received 18 and 27 kg m^{-2} of DMC (Fig. 12).

CONCLUSIONS

Based on two years data, there was ample evidence to conclude that amending an urban soil with an abundant amount of dairy manure compost prior to installing ornamental and turf plants will improve the long-term performance of those plants. The increased performance is probably due to greater levels of soil fertility, including major and minor essential plant nutrients, and improved soil physical properties, such as increased water infiltration and reduced soil compaction. Large repeated applications of dairy manure compost should be avoided to prevent excessive accumulation of soil phosphorus.

REFERENCES

Bradford, J.M. 1980. The penetration resistance in a soil with well-defined structural units. Soil Sci. Soc. Am. J. 44:601-606.

Lowery, Birl and J.E. Morrison, Jr. 2002. Soil Penetrometers and Penetrability. p. 363-388. *In* J.H. Dan and G. Clark Topp (eds). Methods of Soil Analysis. Part 4. Physical Methods. Soil Sci. Soc. Am., Inc. Madison, WI.

Table 1. Selected chemical and physical properties of composted dairy manure applied to landscape plots.

Parameter		Mean	SD
Total N (g kg^{-1})		9.0	(4.3)
Total P (g kg^{-1})		1.04	(0.08)
Total K (mg kg^{-1})		4.90	(0.48)
Ash Content (%)		81.3	(1.1)
OM Content (%)		18.7	(1.1)
Wet Bulk Density (kg m^{-3})		792	(19.9)
Moisture Content (%)		34.3	(1.4)

Table 2. Composted dairy manure application rates and corresponding N, P, and K rates.

Compost Rate	N Rate	P Rate	K Rate
(kg m^{-2})	(g m^{-2})	(g m^{-2})	(g m^{-2})
9	81	9.4	44
18	162	18.8	88
27	243	28.2	132

Table 3. Effect of dairy manure compost on plant available nutrients at the end of the second growing season.

Compost Rate	OM	NO3-N	P	K	S	Fe	Zn	Cu
(ton/A)	(%)	---------------------------------- mg/kg						-------------------------------
		0-7.5cm						
0	3.9	4.8	40	392	39.0	16.6	0.6	0.7
9	5.0	4.0	89	414	47.5	18.4	1.6	0.8
18	5.0	4.0	128	567	48.5	23.1	3.5	1.3
27	5.2	5.0	177	583	52.5	23.5	4.5	1.5
	†	ns	***	***	**	**	***	***
		7.5-15cm						
0	3.9	3.0	18	353	34.5	16.5	0.3	0.7
9	3.8	3.0	34	410	37.5	17.7	0.7	0.8
18	4.1	3.8	58	532	40.3	19.1	1.5	0.9
27	4.1	3.8	64	577	40.3	18.6	1.8	1.0
	ns	**	***	***	**	*	***	***

ns, † ,*, **, *** Not significant and significant at the 0.10, 0.05, 0.01, and 0.001 level of probability, respectively.

Ilex cornuta 'Burfordii Nana' – "Dwarf Burford Holly"

Ilex vomitoria –"Dwarf Yaupon Holly"

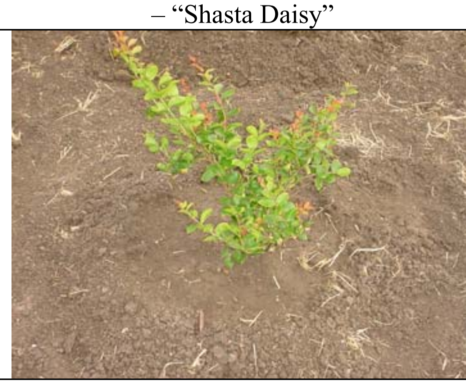
Pentas lanceolata – "Egyptian Star Flower"

Lantana 'New Gold' – "New Gold Lantana"

Echinacea purpurea 'Magnus' – "Purple Coneflower"

Leucanthemum x superbum 'Crazy Daisy'
– "Shasta Daisy"

Rosa 'Knockout' – "Knockout Rose"



Lagerstroemia indica – "Crapemyrtle"

Fig. 1. Species and common names of the eight ornamental plants used in the dairy manure compost urban landscape plots. Plants are shown one day after transplanting during the first growing season. Annual plants were replaced each spring.

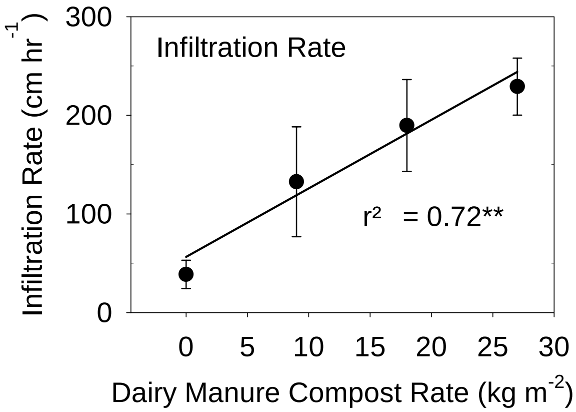


Fig. 2. Effect of dairy manure compost application rate on water infiltration eighteen months after application.

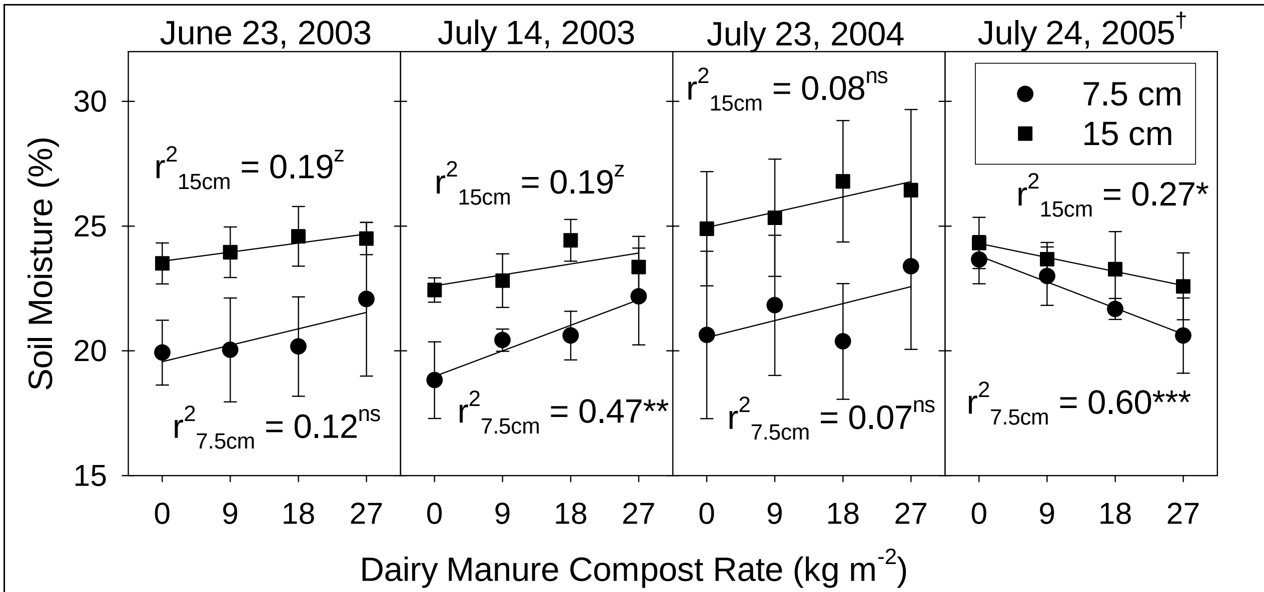


Fig. 3. Effect of dairy manure compost application rate on soil moisture at 7.5 and 15 cm depths at two sampling dates during the first growing season, one sampling date the second growing and third growing seasons. †Irrigation was not applied to turf plants during the 2005 growing season. (ns, z, and ** not significant or significant at the 0.10 and 0.01 levels of probability, respectively.)

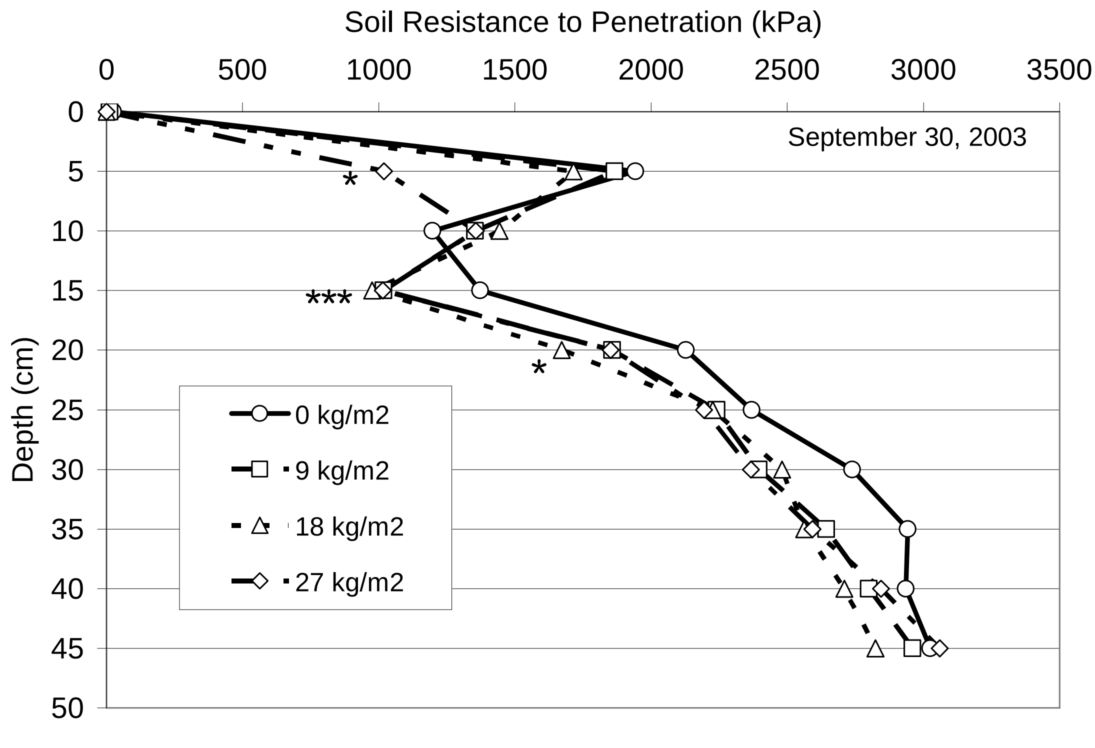


Fig. 4. Effect of dairy manure compost on soil compaction after the first growing season (2003). *, *** Dairy manure compost significantly reduced penetrometer measurements at the 0.05 and 0.001 levels of probability, respectively.

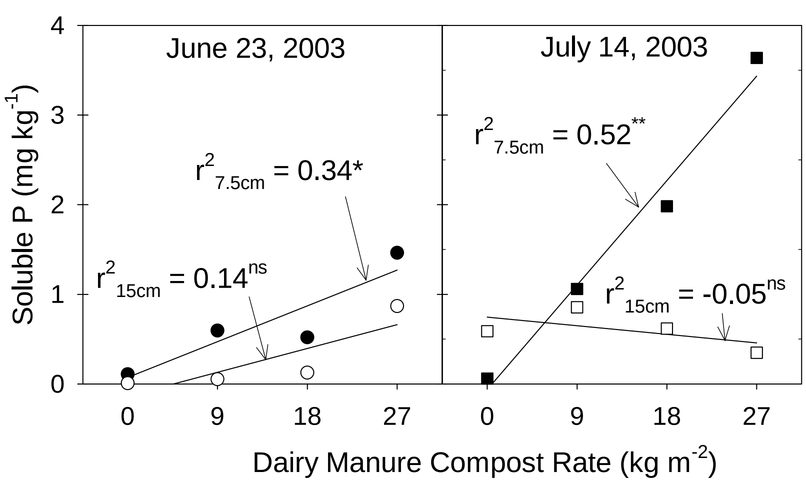


Fig 5. Effect of dairy manure compost application rate on soluble P at 7.5 and 15 cm depths at two sampling dates during the first growing season. (ns, *, ** -- not significant and significant at the 0.05 and 0.01 levels of probability, respectively.)

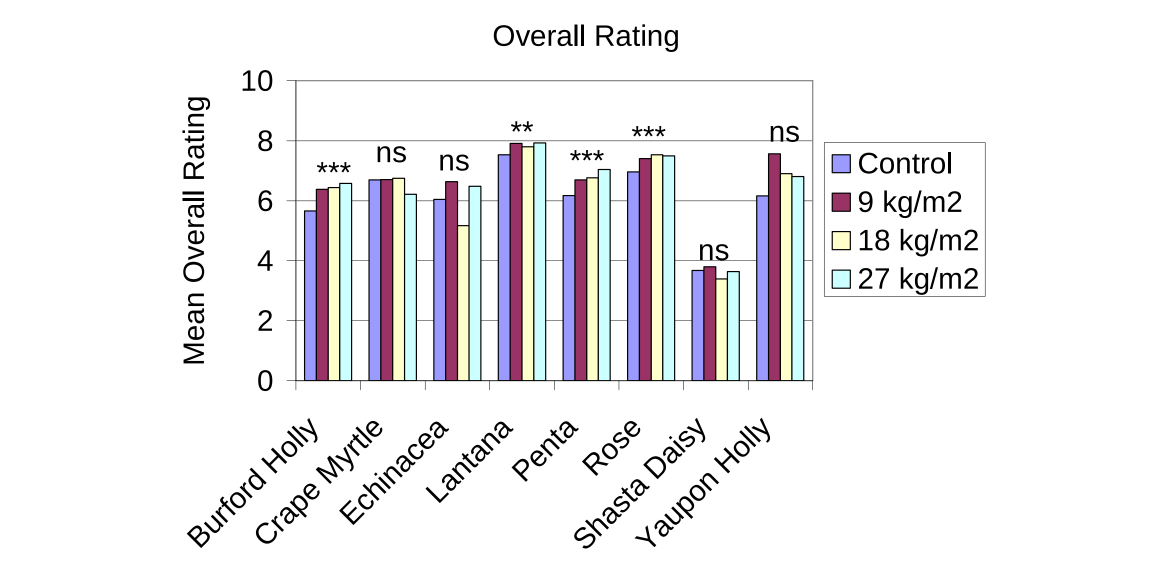


Fig. 6. Effect of dairy manure compost on the two-year mean overall rating for eight ornamental plant species. (ns, **, *** Not significant or significant at the 0.01 and 0.001 levels of probability, respectively.)

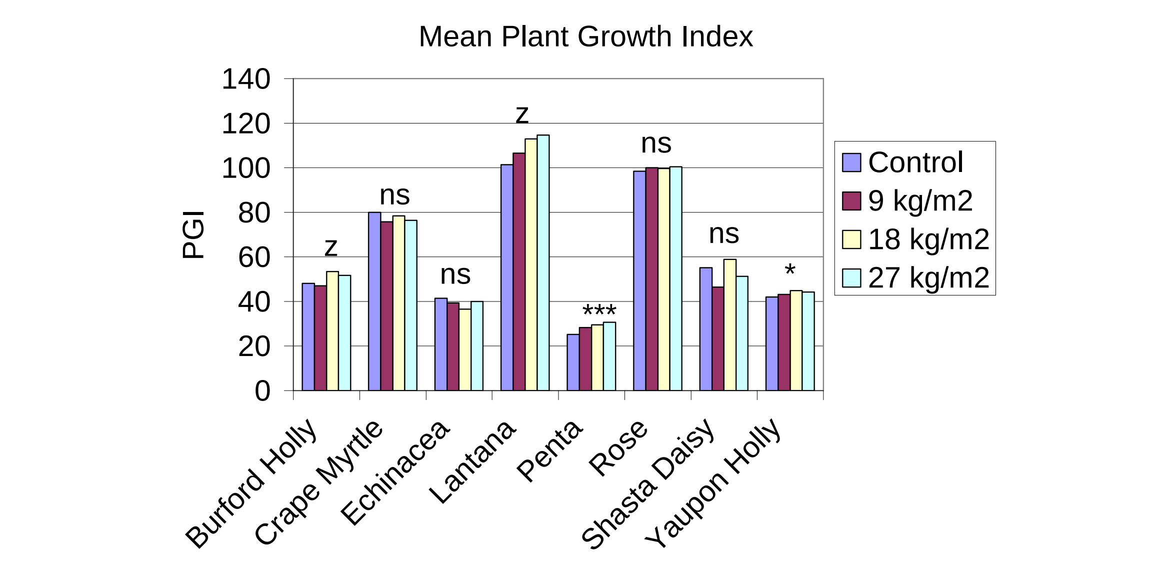


Fig. 7. Effect of dairy manure compost on the two-year overall plant growth index average for eight ornamental plant species. (ns, z, *, *** Not significant or significant at the 0.10, 0.05, and 0.001 levels of probability, respectively.)

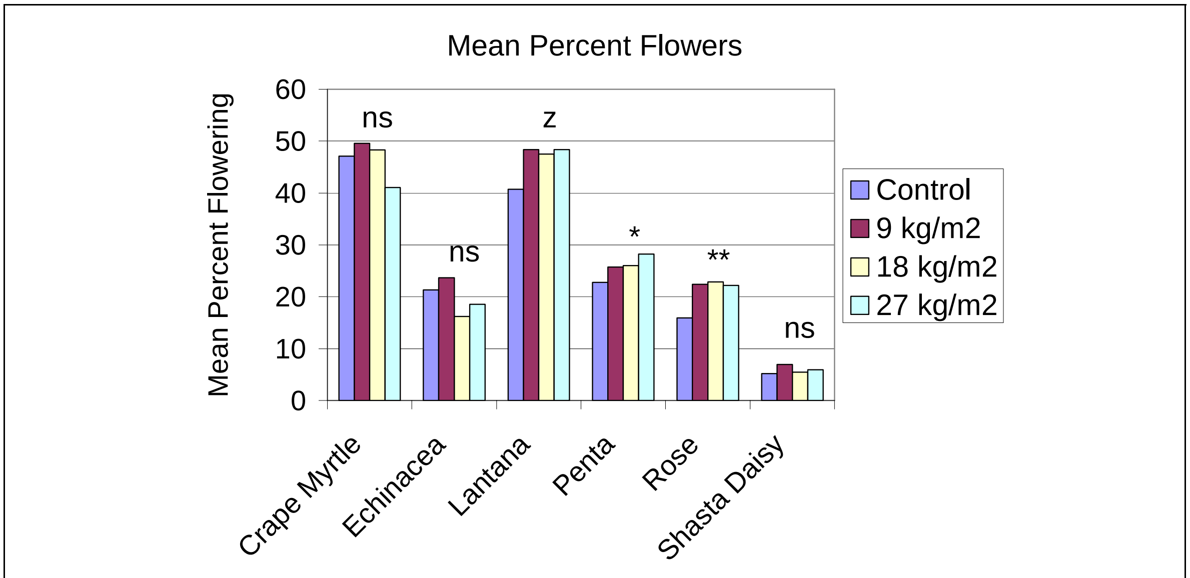


Fig. 8. Effect of dairy manure compost on the two-year overall mean percent flower coverage for six ornamental plant species. (ns, z, *, ** Not significant or significant at the 0.10, 0.05, and 0.01 levels of probability, respectively.)

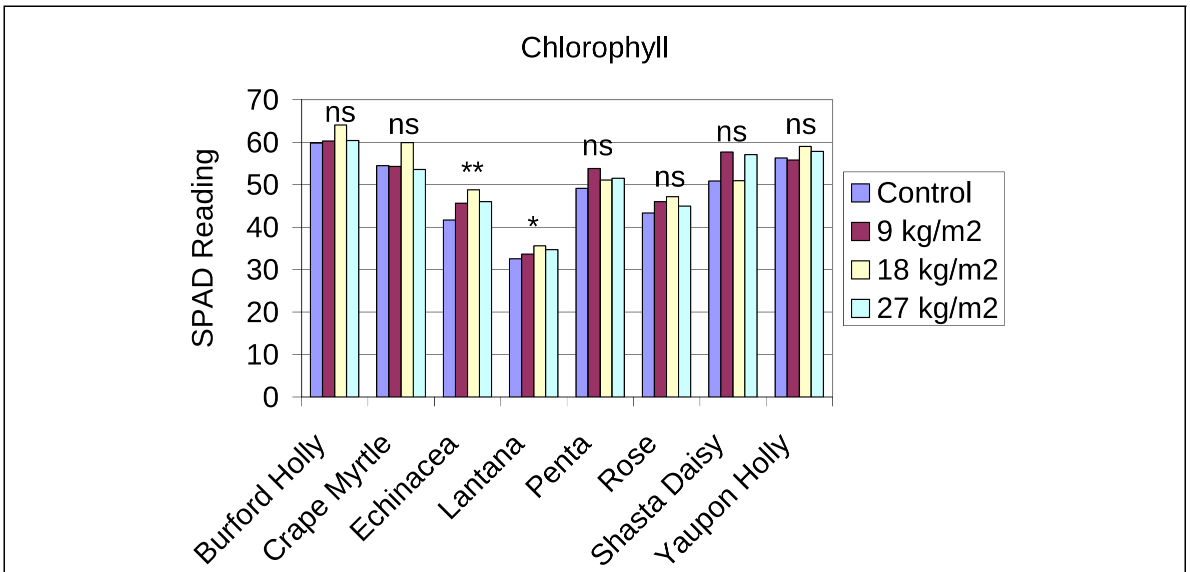


Fig. 9. Effect of dairy manure compost on the two-year mean chlorophyll rating for six ornamental plant species. (ns, *, ** Not significant or significant at the 0.05, and 0.01 levels of probability, respectively.)

Fig.10. Lantana stems shed their leaves during the winter months leaving behind dead and dry stems in the spring.

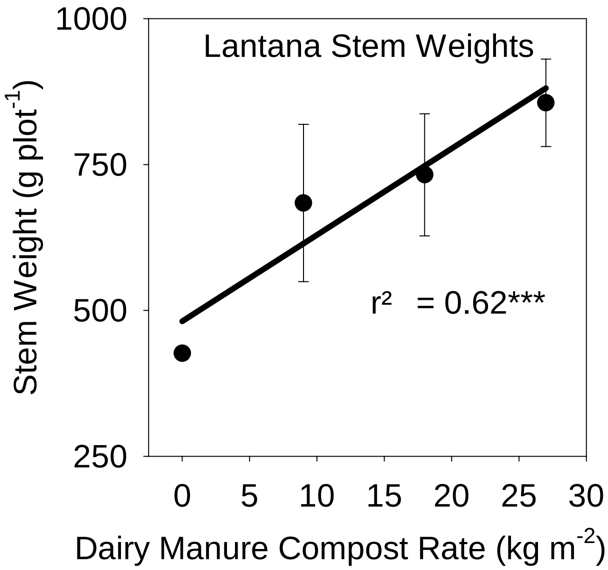


Fig. 11. The weight of harvested Lantana stems significantly increased with increasing dairy manure compost application rate ($p<0.001$).

Fig. 12. Lantana plants reemerging in the spring from a plot that initially received 27 kg m^{-2} dairy manure compost.

Urban Uses for Composted Dairy Manure: Effects on Turfgrass

John J. Sloan and Jim McAfee
Texas A&M University Research and Extension Center at Dallas

BACKGROUND

Turf grass is perhaps the single most important plant in the urban landscape due to the large area it occupies and its ability to protect the soil surface from erosion. Installation of sod following construction of new homes and businesses is an effective way to quickly protect soil that was severely disturbed and degraded by the construction process. Unfortunately, very little post-construction landscaping is devoted to improvement of the soil so that turf and other ornamental plants will be better prepared for long-term healthy growth. Surface soil is commonly removed prior to construction and the remaining subsoil is often mixed with construction debris prior to establishing plants in the landscape. Although ornamental plants and turf grasses planted in these disturbed soils may perform well in the short term due to abundant watering and fertilization, they frequently decline with time when heat and drought stress become prevalent. Dairy manure compost (DMC) is a readily available soil organic matter amendment in many areas due to the presence of large dairy operations. These dairy operations need alternative ways to dispose of their manure because soils surrounding the diary operations are often elevated in soil P. Consequently, dairy farmers and state regulatory agencies are considering urban markets for composted dairy manure.

OBJECTIVES

The overall objective of this study was to evaluate the effect of large single applications of dairy manure compost on the establishment and subsequent growth of typical urban landscape plants and to evaluate the effects on soil chemical and physical properties. This report covers the turf grass component of the research project. Several specific objectives were addressed with the turf grass research.

1. How did increasing rates of dairy manure compost affect the color, density and quality of turf during each year after application?
2. Did the effect of dairy manure compost on turf growth decrease over time after the initial application?
3. How did dairy manure application rate affect turf response to supplemental inorganic N fertilization during the second year of the study?
4. What were the effects of dairy manure application rate on turf biomass production and nutrient content three years after application?

PROCEDURE

Experimental plots measuring 6x6 m were established on a fallow agricultural field. Dairy manure compost purchased from Erath Earth Compost, Dublin Texas was applied at rates of 0, 9, 18, and 27 kg m^{-2} (equivalent to 0, 40, 80, and 120 ton $acre^{-1}$ or approximately 0, 0.5, 1, and 2 inches). Compost was incorporated into the soil using a field cultivator. Selected chemical and physical properties of the compost are shown in Table 1 of the main project summary. Compost applications supplied large amounts of N, P, and K to the soil (Table 2 of main project summary). Following the application and incorporation of compost, one half of each plot (3x6 m) was established with Bermudagrass sod. The other half was established with a variety of ornamental plants and those results are reported in the main project summary.

Data collection began following establishment of sod on the research plots. Turf color, density and quality were rated with a scale of 1 to 9 with 1 indicating complete loss of turf and 9 indicating optimal turf condition. Turf ratings were performed every two weeks during the 2003 and 2004 growing season, and once during the 2005 season. Additionally, percent weed cover was evaluated two times during the third (2005) growing season. Grass clippings were collected one time during the third (2005) growing season. Clippings were weighed to determine above-ground biomass production. A sub sample of the clippings was dried, ground, and analyzed for total nutrient content (N, P, K, and Zn).

RESULTS

Color, Density, and Quality

Dairy manure compost significantly increased Bermuda grass color and quality ratings during the first year after application (Fig. 1, Fig. 2A and 4A) and also increased turf density during the later part of the growing season (Fig. 3A). DMC amendments had the greatest effect on turf color, density, and quality ratings during the second year after application (Figs. 2B, 3B, and 4B), but the effects were still visible 3 years after application, especially for color and quality ratings (Figs. 2C, 3C, and 4C). Turf ratings were only collect one time during the third (2005) growing season, but the results are meaningful given the fact that no irrigation was applied to the turf plots during that atypically dry summer. The 2005 data also shows the effect of supplementing the turf plots with 15 g/m^2 N during the 2004 growing season (Figs. 2C, 3C, and 4C). Supplemental N increased the color, density, and quality ratings for the control plots, but its effect was less apparent in the plots amended with dairy manure compost. The large effect of DMC on bermudagrass color, density, and quality ratings was mostly due to the large amount of N, P, K and micronutrients supplied by the compost. The fact that the effects persisted 3 years after application with no additional fertilization supports the idea of using DMC to establish urban landscapes.

Turf Biomass

Bermuda grass clippings weights were measured during late summer of the third year after application of dairy manure compost. In the absence of additional supplemental fertilization, Bermuda grass growth was significantly increased by dairy manure compost (Fig. 5A). Obviously, the level of nutrients in the soil three years after compost application was sufficient to promote healthy turf growth. The dry matter content of the Bermuda clippings (Fig. 5B) decreased with DMC application rate showing that DMC also increased the lushness, and thus quality, of Bermuda grass. An adequate supply of nitrogen is particularly important for healthy, succulent, plant growth.

Turf Nutrient Content

Dairy manure compost significantly increased the concentration on major and micro nutrients (N, P, K, and Zn) in Bermuda grass clippings collected during the third year after application (Fig. 6). Turf tissue analysis shows that nutrients supplied by dairy manure compost remain available to plants three years after application and eliminate the need for additional fertilization. The data also suggests that the DMC nutrients will continue to be adequate for plant growth in subsequent growing seasons with little or no need for supplemental fertilization. The turf tissue analysis corroborates the visual ratings of turf color, density, and quality, and also explains the increase in turf biomass production with increasing rate of DMC application.

Weed Invasions

Turf grass that becomes stressed due to lack of water and nutrients is susceptible to invasion by undesirable weeds. During the middle of the third growing season (June 2005) after application of dairy manure compost, the percentage of each turf plot covered with weeds was visually estimated (Table 1). Half of each plot had received supplemental nitrogen during the second growing season (3 applications of 5 g/m^2). Weed invasions were generally low ($\leq$2%) in all plots that were previously amended with dairy manure compost, regardless of whether or not they received supplemental N fertilization. Weed invasion was also low for the control plot that received supplemental fertilization during the second growing season. However, in the control plot that received no dairy manure compost and no supplemental N fertilizer, there was a significantly greater percentage of weed coverage (Table 1 and Fig. 1). The weed data shows the importance of nitrogen fertilization for maintaining high quality turf that will not be susceptible to weed invasions, especially during droughty conditions such as those prevalent during the third (2005) growing season when no irrigation was applies to the turf plots.

CONCLUSION

Amending a calcareous clay-textured soil with dairy manure compost had a beneficial effect on the establishment and subsequent 3-year performance of Bermuda grass turf. Turf in the compost-amended soils was greener, exhibited more growth, and contained more nutrients than turf growing in unamended soil. Inorganic nitrogen fertilizer produced many of the same beneficial affects observed for dairy manure compost, but N fertilization was unnecessary in the compost-amended plots. It is likely that Bermuda grass turf will continue to perform well in soils amended with dairy manure compost due to the elevated levels of available plant nutrients. Given the positive effects of dairy manure compost on Bermudagrass turf performance, along with the improved growth of ornamental plants reported in the main project summary, it is clear that the application of 9 to 20 kg/m^2 dairy manure compost (equivalent to 0.5 to 2 inches) is a very effective way to create and sustain a high quality urban landscape.

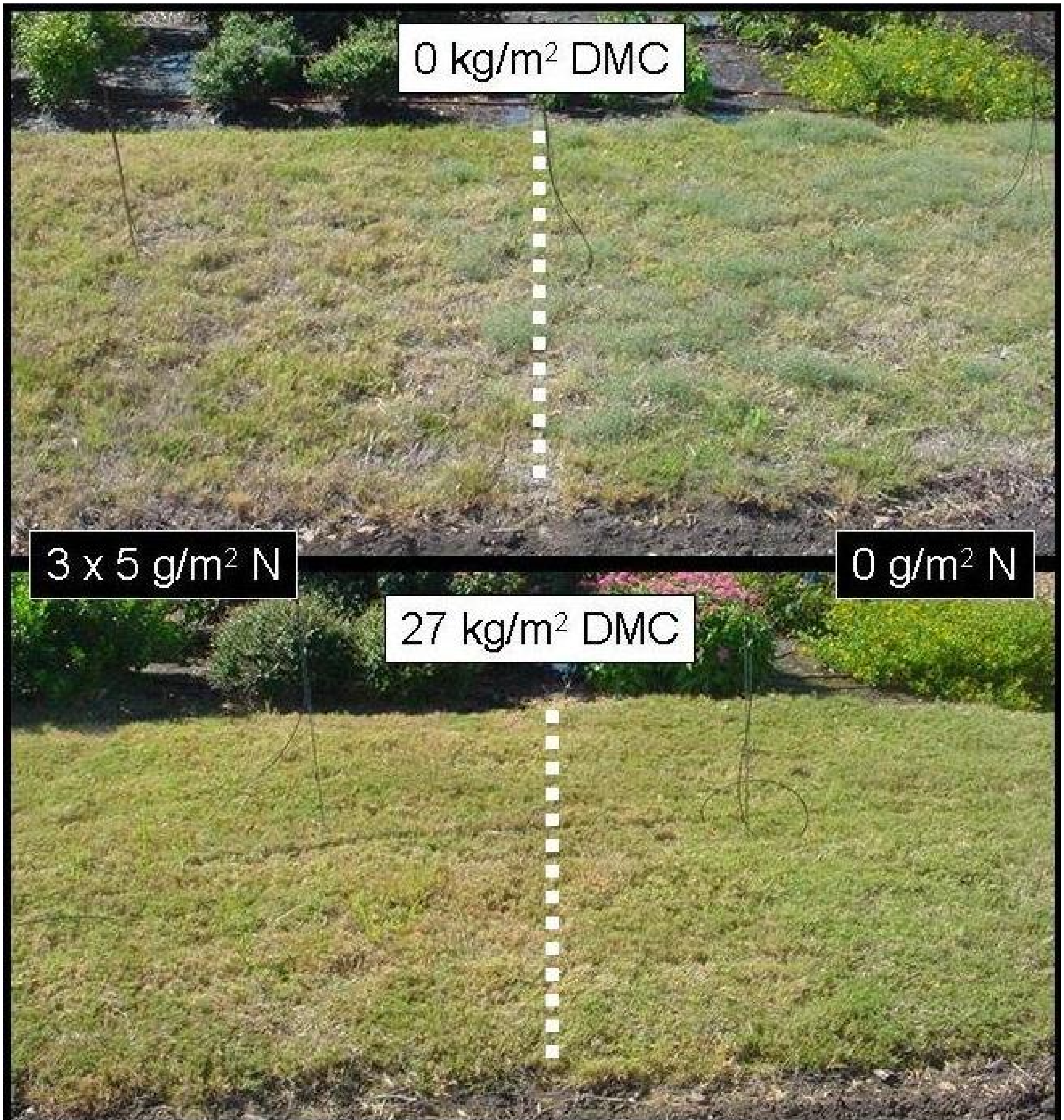


Fig. 1. Comparison of Bermuda grass quality three years after application of 0 and 27 kg/m^2 dairy manure compost. The left half of each plot was supplemented with a total of 15 g/m^2 N during the second growing season.

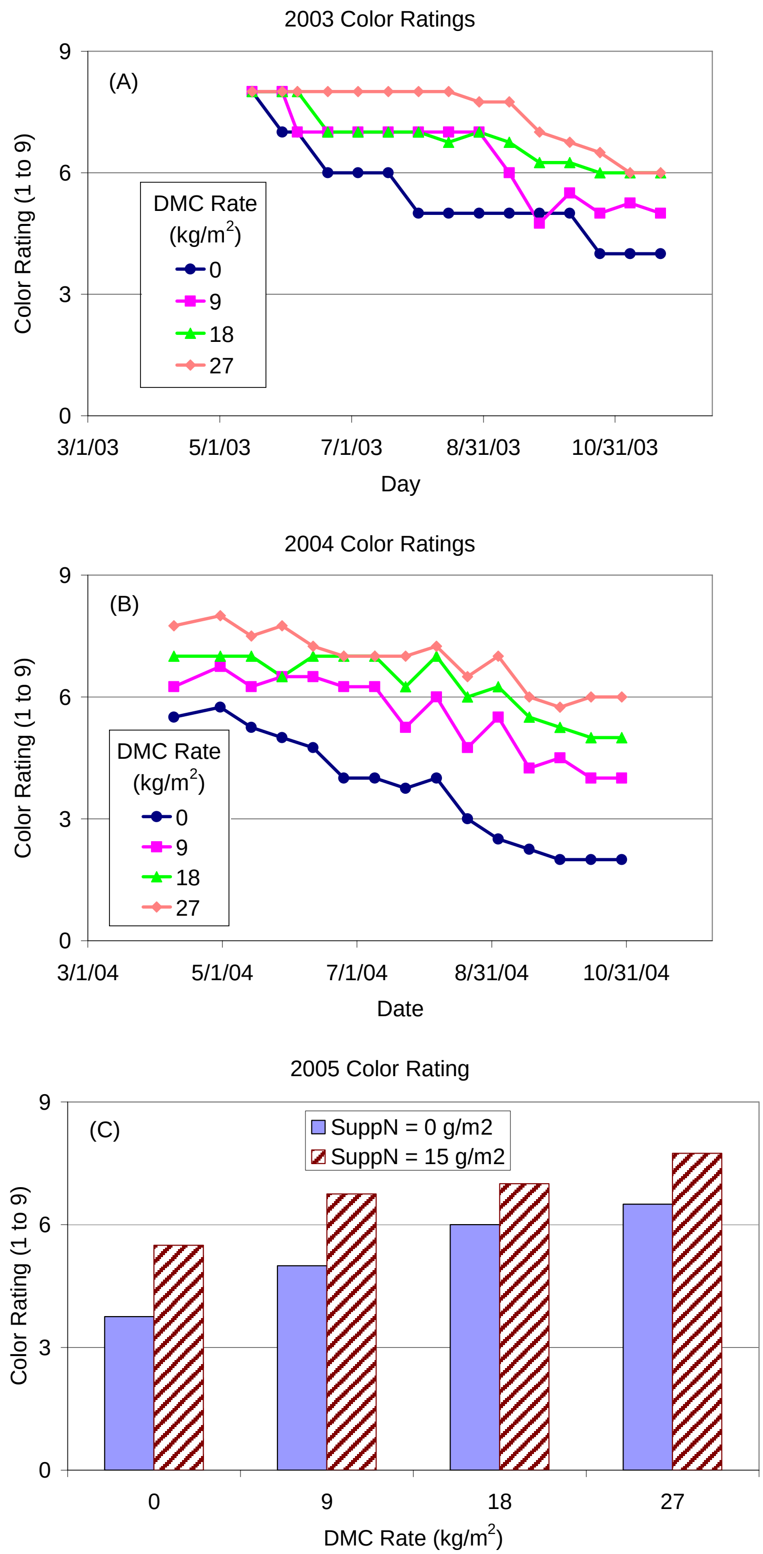


Fig. 2. Effect of 0, 9, 18, and 27 kg/m^2 dairy manure compost (DMC) on Bermudagrass turf color ratings during the year of application (A) and two (B) or three (C) years after application.

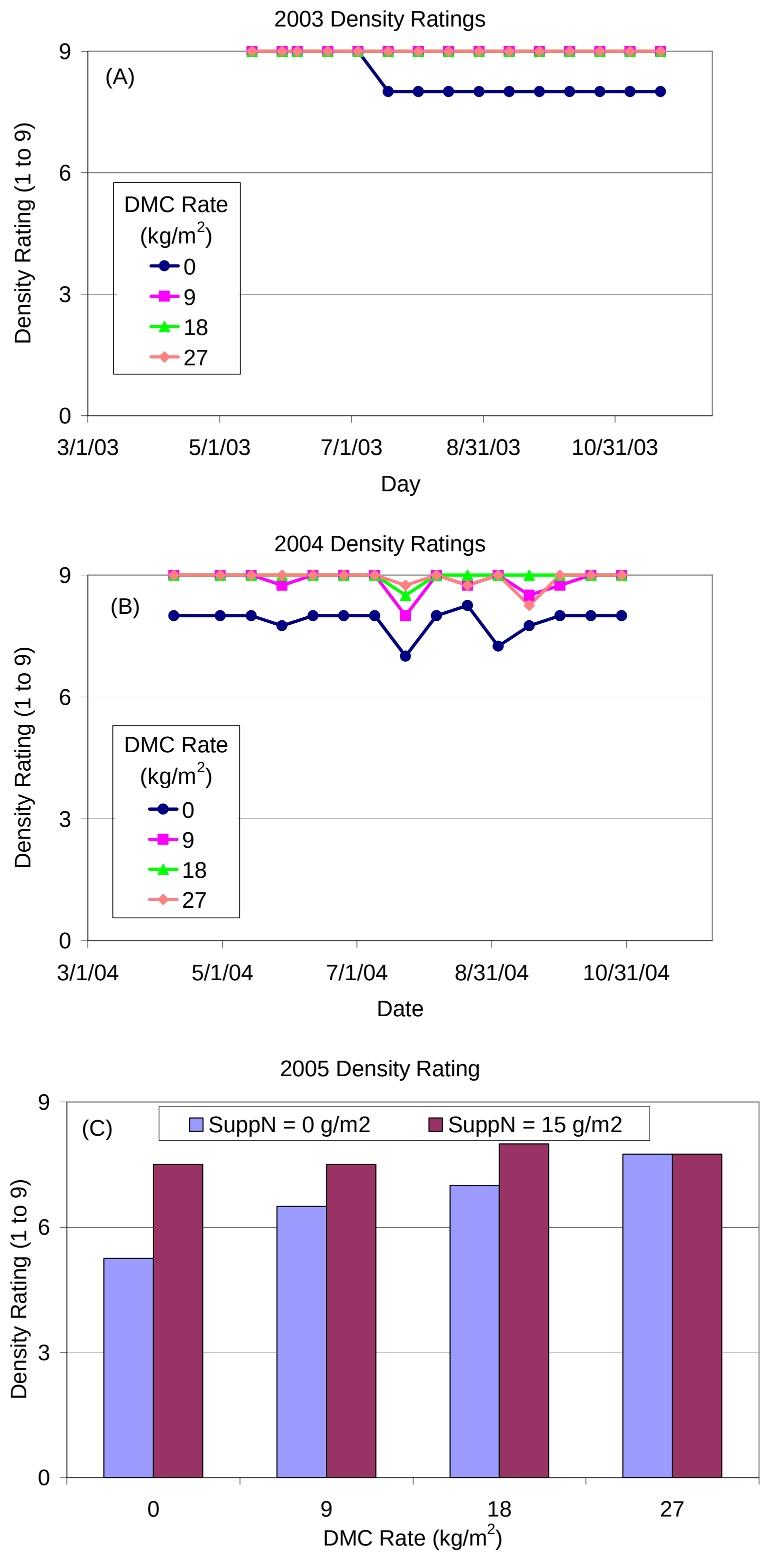


Fig. 3. Effect of 0, 9, 18, and 27 kg/m^2 dairy manure compost (DMC) on Bermudagrass turf density ratings during the year of application (A) and two (B) or three (C) years after application.

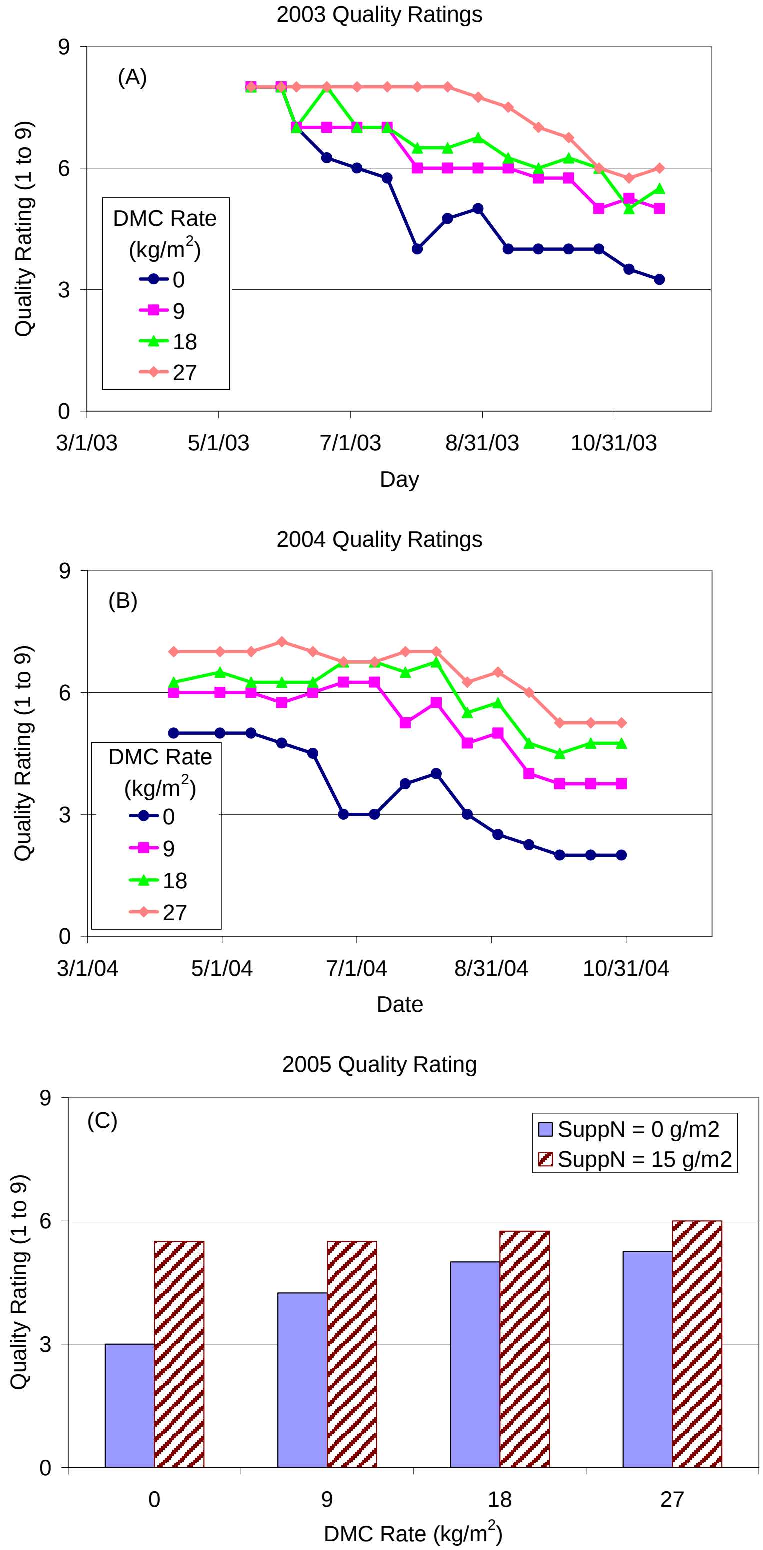


Fig. 4. Effect of 0, 9, 18, and 27 kg/m^2 dairy manure compost (DMC) on Bermudagrass turf quality ratings during the year of application (A) and two (B) or three (C) years after application.

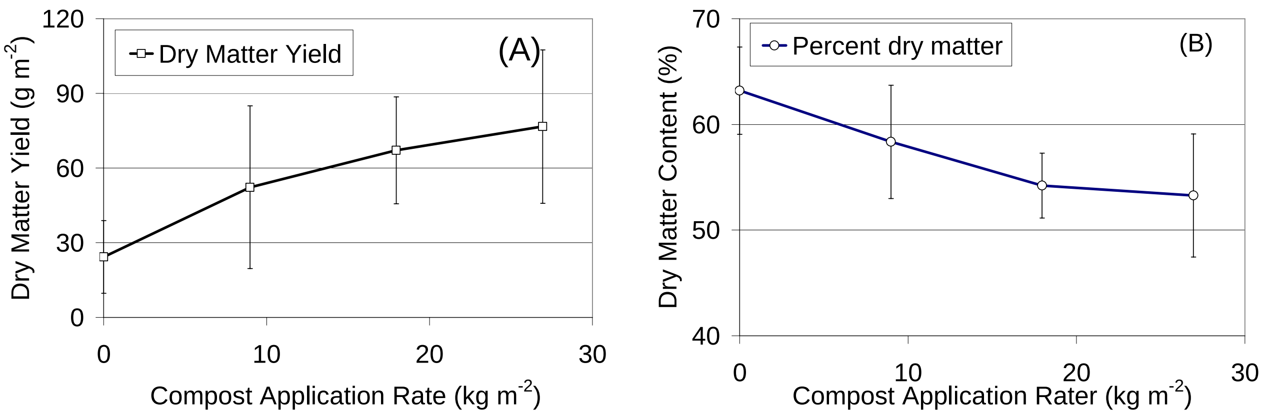


Fig. 5. Effect of dairy manure compost application rate on (A) bermudagrass clipping weights and (B) dry matter content of grass clippings.

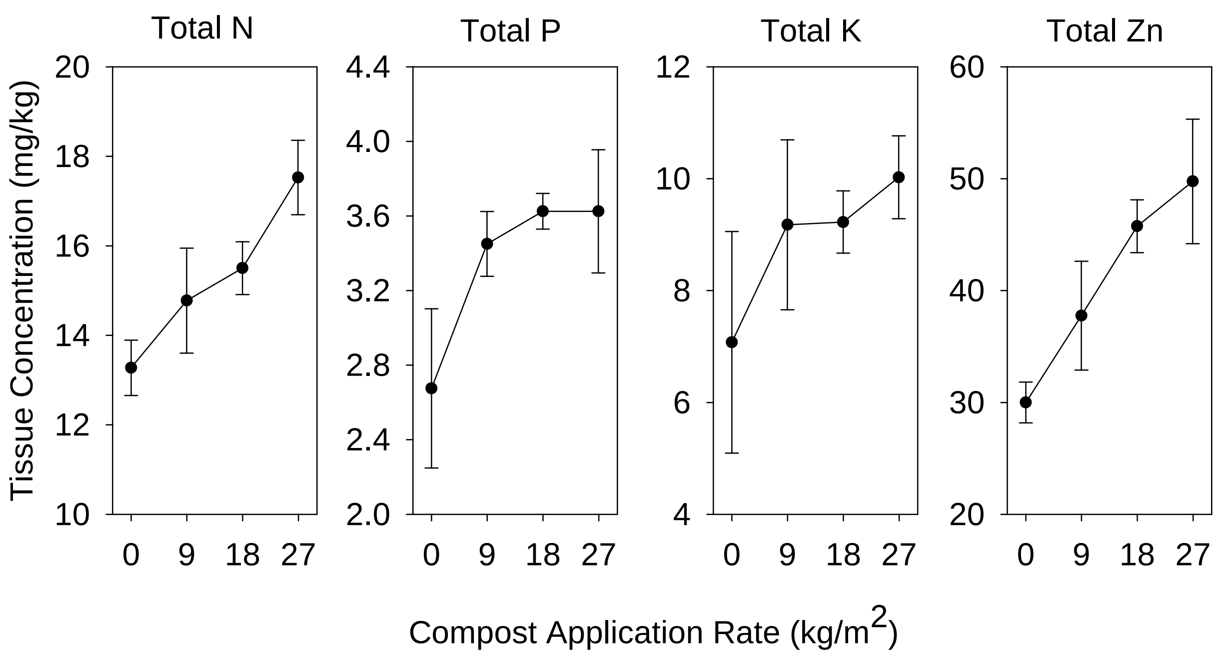


Fig. 6. Effect of 0, 9, 18, and 27 kg/m^2 dairy manure compost on the concentration of N, P, K, and Zn in Bermuda grass tissue harvest near the end of the third growing season after application.

Table 1. Effect of dairy manure compost rate and the addition of supplemental N on weed invasions during the third year after compost application. Values within a column followed by the same letter are not statistically different (LSD, $p \leq 0.05$).

DMC Rate	Weed Coverage (%)[z]	
(kg/ha)	0 g/m^2 N	15 g/m^2 N[y]
0	13 a	<1 a
9	<1 b	2 a
18	<1 b	<1 a
27	<1 b	<1 a

[z] Statistical analysis was performed on log transformed data.

[y] Supplemental N was applied during the second growing season in three applications of 5 g/m^2.

Effects of Dairy Manure Compost Application Timing on Coastal Bermudagrass

INTRODUCTION

Dairy manure compost is a good source of nutrients for vegetation especially when supplemented with commercial nitrogen fertilizer. The level of nitrogen supplementation required can vary based on the forage producer's yields and goals for overall quality. By determining the best possible dairy manure compost and nitrogen fertilizer rates and timings, better recommendations can be made to those utilizing the compost on their property. Research was conducted to compare the effects of composted dairy manure and raw dairy manure alone, or in combination with supplemental inorganic fertilizer on soil chemical properties, and Coastal Bermudagrass yield and quality.

OBJECTIVE

The primary objective of this demonstration was to determine the effects of compost application timing and rate on yield of coastal Bermudagrass.

MATERIALS AND METHODS

This study was conducted at the Stephenville Research and Demonstration Center in Erath County which consists of a May fine sandy loam with a 0 to 1 percent slope.

The study consisted of 27 treatments that included three compost rates applied at three different times and supplemented with 0, 50, and 100 lbs/acre of a commercial nitrogen fertilizer (Table 1) The dairy manure compost was hand applied on November 20, 2002, January 22, 2003, and March 10, 2003. The commercial fertilizer applications were also made of March 10, 2003.

Plots were harvested by cutting a 4.33 foot strip from the center of each plot with an Almaco forage harvester. A grab sample was also taken to determine the moisture content and forage quality of the Bermudagrass.

RESULTS

Comparison yields in 2003 showed no significant differences between November and March applications of compost. Also, there was no significant difference between the supplemental rate on 50 or 100 lbs nitrogen per acre with the exception of the January application at the 200 N rate (Table 2) In all cases, the 50 and 100 lb rates of supplemental nitrogen were statistically lower than both the November and March application under all supplemental nitrogen applications.

Again in 2004, there was no significant difference in yield between the November and March applications of compost at all rates. In three of six instances, the application of 100 lbs of supplemental nitrogen was statistically better than the 50 lb rate indicating that the compost's ability to supply adequate nitrogen in the second year is somewhat reduced. In all cases, supplemental nitrogen at the 50 and 100 lb rates produced significantly better yields than compost without supplemental nitrogen. The January compost application again produced unusual results with the yields being reduced as application rates went up.

Table 1. Displays the application timing, compost rate, and fertilizer rate applied to each treatment.

Treatment Number	**Application Timing**	**Compost Rate ton/A**	***Rate of Fertilizer per cutting* lb/A**
1	Nov 20, 2002	8	0-0-0
2	Nov 20, 2002	8	100-0-0
3	Nov 20, 2002	16	0-0-0
4	Nov 20, 2002	16	100-0-0
5	Nov 20, 2002	32	0-0-0
6	Nov 20, 2002	32	100-0-0
7	Jan 22, 2003	8	0-0-0
8	Jan 22, 2003	8	50-0-0
9	Jan 22, 2003	8	100-0-0
10	Jan 22, 2003	16	0-0-0
11	Jan 22, 2003	16	50-0-0
12	Jan 22, 2003	16	100-0-0
13	Jan 22, 2003	32	0-0-0
14	Jan 22, 2003	32	50-0-0
15	Jan 22, 2003	32	100-0-0
16	Mar 10, 2003	8	0-0-0
17	Mar 10, 2003	8	50-0-0
18	Mar 10, 2003	8	100-0-0
19	Mar 10, 2003	16	0-0-0
20	Mar 10, 2003	16	50-0-0
21	Mar 10, 2003	16	100-0-0
22	Mar 10, 2003	32	0-0-0
23	Mar 10, 2003	32	50-0-0
24	Mar 10, 2003	32	100-0-0
25	Untreated Check	0	0-0-0
26	Control	0	100-0-0
27	Control	0	100-100-150

Table 2. Effects on N Rate and Application Timing on Coastal Bermudagrass Yield (lbs/acre)- Compost at 200 N Rate, 2003

Application Timing	Nitrogen Rate			
	0*	50	100	Average
November*	10,040 ab B	----	17,092 A	13,566
January	9,042 b C	15,725 B	17,913 A	14,227
March	10,422 aB	16,533 A	17,637 A	14,864
Average	9,835	16,129	17,547	

*Means within a column followed by a similar lower case letter or with in a row followed by a similar upper case letter do not differ (P=.05, LSD)

CONCLUSION

Effects of compost application timing should be most prevalent in the first season after applications. The results of this study do not provide any clear statistical data that application in November, January, or March significantly affected forage yields in 2003. While there are some statistical differences when comparing the January to November and March applications, these do not follow a pattern that one would expect when considering possible nutrient loss from early applications or lack of nutrient availability from late applications. Application timing also had little influence on crude protein levels.

Compost without supplemental nitrogen produced good yields in 2003 with averages in the 4 to 5 ton range, but crude protein levels were 10% or less. The addition of 50 lbs of nitrogen made significant improvements in both yields and crude protein levels. In most instances in 2003, the application of 100 lbs of supplemental nitrogen did not significantly increase forage yield although crude protein levels were higher in all cases. In 2004, average yields without supplemental nitrogen had fallen to less than 4 tons/acre. These yields were doubled by the application of 50 lbs of supplemental nitrogen. In this second year, 100 lbs of supplemental nitrogen was significantly better than 50 lbs of nitrogen in 50% of cases. There results would be expected as the nitrogen in the compost becomes depleted.

Dairy manure compost is a good source of nutrients especially when supplemented with commercial nitrogen fertilizer. The level of supplementation depends on the forage producer's yield and quality goals. It would be necessary to increase supplementation as nitrogen levels are depleted over time to maintain yields and crude protein levels. Timing of compost application showed little influence on forage yields. Climatic conditions such as temperature and rainfall following the application can have large influences on both the loss of nutrients (especially nitrogen) if the compost is applied too early and the availability of nutrients if the compost is applied too near the growing season. Producers should also consider costs associated with transport and application of this material and weigh them against the cost of commercial fertilizers.

Effects of Dairy Manure Compost Application Rate on Coastal Bermudagrass

INTRODUCTION

Livestock manure has been applied throughout recorded history as a soil amendment to improve soil quality, and supply nutrients to forage and row crops. However, long term application of livestock manure to field can cause an accumulation of nutrients in excess of what the plant requires for growth and sustainability. The dairy industry in North Central Texas faces significant environmental challenges related to management of livestock manure generated by concentrated animal feeding operations. To add to the management challenges, manures are expensive to transport because they generally have high moisture content (50-80%) and low nutrient concentrations compared to inorganic fertilizer. Although removal and utilization of manure outside the Bosque watershed is a preferred solution, transportation costs limit the distribution radius and economic feasibility of this option.

This field study was conducted on an established non-irrigated Coastal Bermudagrass field at the Texas A&M University Agricultural Research and Extension Center near Stephenville, Texas in 2002 and 2003. Research was conducted to compare the effects of composted dairy manure and raw dairy manure alone or in combination with supplemental inorganic fertilizer on soil chemical properties, and Coastal Bermudagrass yield and quality.

OBJECTIVE

To evaluate various compost rates on the establishment and growth of coastal Bermudagrass as well as evaluate various application methods and timings of compost on coastal Bermudagrass.

METHODS AND MATERIALS

Sixty-six plots, each 3- by 6-m, were established at the site and received treatments containing dairy manure compost or raw dairy manure alone or in combination with supplemental rates of inorganic N, P and/or K. Soils were sampled from test plots in Stephenville prior to treatment. Dairy compost and raw manure were applied at various rates and Coastal Bermudagrass were planted at typical seeding rates. Plots were harvested monthly with an ALMACO forage harvester and samples were taken from each plot. Supplemental rates of synthetic fertilizer per treatment were added following each harvest. Treatments were arranged in a randomized complete block design with three replications. Initial compost, manure and inorganic fertilizer treatments were surface applied by hand at spring green up with subsequent applications of inorganic fertilizer for selected treatments being applied after each harvest. Dairy manure compost and raw manure were applied only at the initiation of the study with the exception of the two C1 (14.3 Mg ha^{-1}) treatments, which were applied annually. A summary of all treatments applied is provided in Table 1.

Table 1. Treatment Summary.

Treatment Number	Treatments	Year 1 Harvest			Year 2 Harvest		
		1	2	3	1	2	3
1	Manure (32 tons/A)	X					
2	Manure (32 tons/A)	X	N	N	N	N	N
3	Manure (32 tons/A)	XN_1	N_1	N_1	N_1	N_1	N_1
4	Manure (32 tons/A)	X	N_2	N_2	N_2	N_2	N_2
5	Manure (32 tons/A)	X	NP	N	NP	N	N
6	Manure (32 tons/A)	X	NK	NK	NK	NK	NK
7	Compost (16 tons/A)	X	--	--	--	--	--
8	Compost (16 tons/A)	X	N	N	N	N	N
9	Compost (16 tons/A)	XN_1	N_1	N_1	N_1	N_1	N_1
10	Compost (16 tons/A)	X	N_2	N_2	N_2	N_2	N_2
11	Compost (16 tons/A)	X	NP	N	NP	N	N
12	Compost (16 tons/A)	X	NK	NK	NK	NK	NK
13	Compost (32 tons/A)	X	--	--	--	--	--
14	Compost (32 tons/A)	X	N	N	N	N	N
15	Compost (32 tons/A)	XN_1	N_1	N_1	N_1	N_1	N_1
16	Compost (32 tons/A)	X	N_2	N_2	N_2	N_2	N_2
17	Compost (32 tons/A)	X	NP	N	NP	N	N
18	Compost (32 tons/A)	X	NK	NK	NK	NK	NK
19	Compost (8 tons/A)	XN_1	N_1	N_1	XN_1	N_1	N_1
20	Compost (8 tons/A)	X	N	N	XN	N	N
21	Untreated check	--	--	--	--	--	--
22	Commercial Fertilizer (100-100-150)	X	XF_1	XF_1	XF_2	XF_1	XF_1

X = Treatment applied
N = Nitrogen (100 lbs/A)
N_1 = Nitrogen (50 lbs/A)
N_2 = Nitrogen (75 lbs/A)
P = P_2O_5 (100 lbs/A)
K = K_2O (100 lbs/A)
F_1 = Commercial Fertilizer at 100-0-100
F_2 = Commercial Fertilizer at 100-100-100

RESULTS

Comparison of yields in 2003 showed no significant difference between November and March applications of compost. Also, there was no significant different between the supplemental rate of 50 or 100 lbs N/acre with the exception of the January application at the 200 lbs N rate.

Composted dairy manure (28.7 and 57.3 dry Mg ha-1) or raw manure alone increased cumulative forage yields compared to the untreated check in both years of the study, but were less than those obtained using only inorganic fertilizer. Application of 56 kg N ha-1 cutting-1 or more of supplemental N to compost (28.7 and 57.3 dry Mg ha-1) or manure produced forage yields that were equal to or greater than those obtained using inorganic fertilizer alone. However, increasing compost rate did not increase tissue N concentrations regardless of supplemental inorganic N rate. Yield and tissue K concentrations were increased in the second growing season when supplemental inorganic K was applied to 29 Mg ha-1 of compost or 54 Mg ha-1 of raw dairy manure. No yield response was observed when supplemental inorganic P was applied to compost or manure.

Soil pH and concentrations of NH4, NO3, K, Ca, Mg and Mn were increased by application of compost or manure. Soil P concentrations in the 0 to 5-cm zone exceeded 200 mg kg-1 when compost was applied at the high rate. Dairy manure compost was an effective nutrient source for Bermudagrass hay production, but will require the use of supplemental N and, in some cases, K to achieve yields comparable to inorganic fertilizer. The results on the coastal Bermudagrass plots can be seen from the plot overviews in Figure 1.

Figure 1: Stephenville plot overview.

CONCLUSION

Raw and composted manures generally act as slow release nutrient sources which can improve nutrient stability in the event of significant rainfall, but also may affect their ability to support rapidly growing, warm season crops. Forage yields produced by compost and raw dairy manure alone were significantly greater than the untreated check, but significantly less than inorganic fertilizer in both years. Increasing supplemental N fertilizer rates produced forage yields in compost and manure plots that were equal to or greater than those in inorganic fertilizer, but may not be adequate to offset increased input costs. Tissue nitrogen concentrations also tended to increase with increasing rates of supplemental N applied to compost or manure.

Using Dairy Manure Compost for Corn Silage

T.J. Butler, J.P. Muir, and L. Lastly

INTRODUCTION

The dairy industry represents a significant component of the southern agricultural economy, having total sales in excess of $24.8 million (USDA, 2001). Erath County contains over 200 dairy cattle operations, each with an estimated 1500 to 2000 cows. With approximately 200,000 cattle in confined animal feeding operations (CAFOs) an estimated 1.8 million metric tons/yr of manure is created (Brazos River Authority, 1993). The USEPA, in a compilation of state reports, has identified agricultural runoff as the cause of impairment of 55% of surveyed river length and 58% of surveyed lake area (USEPA, 1990). There are few options for disposing of waste thus fueling a controversy over the contamination of drinking water. The Upper North Bosque River watershed, located in Erath county, is a small, 160 km long ephemeral river that flows from north of Stephenville south to Lake Waco, and is the sole source of drinking water for about 150,000 people (Siebert, 2002).

Elevated levels of nitrogen (N) and phosphorus (P) concentrations have been reported in several reservoir and stream sites in the Upper North Bosque River watershed (McFarland and Hauck, 1999). As the concentrations of these nutrients increase, there is the potential for eutrophication, a condition where a body of water ceases to sustain a diverse ecosystem due to the concentrations of these nutrients. This promotes algal blooms and reduces dissolved oxygen causing “smelly water” or fish kills as well as human infections from pathogens in animal fecal material. Although many factors contribute to the eutrophication process, economically feasible controls relate to the supply of N and P (Stumm and Morgan, 1981). With potential health threats and an increasing concern about the environment, composting has become an attractive option to turn problem materials and waste into a valuable product, which can then be returned to the land.

OBJECTIVE

The objectives of this study were to 1) determine the optimal composted manure rate on corn silage and 2) evaluate the two compost sources with varying levels of organic matter.

MATERIALS AND METHODS

The field experiment was conducted in 2003, 2004, and 2005 at the Texas A&M Research and Extension Center at Stephenville, TX [32° 13’, 38” N, 98° 12’, 9” W and, 401 m elevation]. The experiment was arranged in a split-plot design with four replications (Hoshmand, 1994). The main plots consisted of varying rates of compost, while subplots consisted of varying rates of N.

In each year, plots consisted of four 3.66 m by 9.14 m rows of corn with 0.91 m between rows and 1.52 m alleys between each replication. In 2003, the main plots consisted of four levels (0, 45, 90, and 135 Mg ha^{-1}) of a commercial source of composted dairy manure from Producers Compost, Stephenville, TX. In 2003 (Study I), Compost analysis averaged 15% OM, 78.2% dry matter (DM), 0.72% N, 0.39% P, and 1.57% K, which contains 5.11 kg N, 6.29 kg P_2O_5 , and 13.43 kg K_2O per wet ton. Subplots consisted of two randomized nitrogen levels (224 kg ha^{-1} and 336 kg ha^{-1}). These treatments were compared to a commercial fertilizer (336-224-112 kg ha^{-1} of N-P_2O_5-K_2O respectively) standard and a true standard (0-0-0). N was applied as a blend of ammonium sulfate and urea 33.5-0-0-12, P was applied as triple super phosphate 0-46-0 and K was applied as muriate of potash 0-0-60.

In 2004 (Study II) main plots consisted of four levels (0, 45, 90, and 135 Mg ha^{-1}) of a commercial source of high quality composted dairy manure (HQC) from Organic Residual Reclamation, Dublin, TX, and three levels (0, 45, and 90 Mg ha^{-1}) of low quality composted dairy manure (LQC) from Producers Compost, Stephenville, TX. The HQC Compost analysis averaged 57% OM, 41.3% DM, 2.40% N, 0.45% P, and 1.36% K, which contains 8.99 kg N, 3.88 kg P_2O_5, and 6.13 kg K_2O per wet ton. The LQC Compost analysis averaged 17% OM, 74.1% DM, 1.13% N, 0.40% P, and 2.02% K, equivalent to 7.60 kg N, 6.14 kg P_2O_5, and 16.34 kg K_2O per wet ton. The subplot treatments in 2004 consisted of 112, 224, 336 Kg ha^{-1} N. These treatments were compared to a commercial fertilizer check (336-224-112, 168-112-100 and 0-0-0 Kg ha^{-1} of N-P_2O_5-K_2O respectively). Compost was disked in 15 cm approximately two months before planting along with a commercial application of $P_2O_5$and K_2O as recommended by the soil test. Half of the N fertilizer was applied the day of planting and the other half was surface applied one month after planting as NH_4NO_3.

Corn variety Triumph 2011RR was seeded (23,000 seeds/acre) in March each year, with a John Deere MaxEmerge 2 planter. After seeding corn in each year, weeds were controlled with a pre-emergent application of atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) at 1.12 Kg ai ha^{-1}. Herbicide applications were applied at 262 kPa with a tractor mounted sprayer equipped with flat fan nozzles (Teejet 8003 flat fan nozzle, Spraying Systems, Co., Wheaton, IL) at 140 L ha^{-1}. Weeds were also controlled with a post-emergent application of glyphosate [N(phosphonomethyl)glycine] at 1.54 kg ai ha^{-1}. Herbicides applications were applied at 207 kPa with a CO_2 backpack sprayer equipped with 4 flat-fan nozzles spaced 48.26 cm apart (Teejet 8002 flat fan nozzle, Spraying Systems Co., Wheaton, IL) at 140 L ha^{-1}.

At harvest, a 3.05 m section of the inner two rows in each subplot were hand-harvested at a 5.08-7.62 cm stubble height when kernels reached one-half milkline. A representative sample of three plants was ground through a three-way Chipper Shredder (MTD Products, Inc., Cleveland, OH.) and a representative sub-sample was collected. Each sample was oven dried at 55°C for three days. Yields were calculated on a DM basis and then converted to Mg ha^{-1} at 35% DM.

RESULTS AND DISCUSSION

Compost Rate - Study I

Year X compost rate and year X N rate interactions were significant; therefore means are reported by year. Compost rate X N rate interaction and N rate effect were not significant, thus means are pooled across main effects. In 2003 (growing season following compost application), corn silage yields increased as compost rate increased, when N was not limiting. The low (45 Mg ha^{-1}) compost rate increased corn silage yield by 27% when compared to no compost applied, which did not differ from the moderate (90 Mg ha^{-1}) compost rate. The high (135 Mg

ha^{-1}) compost rate increased corn silage yields by 44% when compared to no compost application and 11% over the moderate (90 Mg ha^{-1}) compost rate. The moderate (39.7 Mg ha-1) and high (135 Mg ha-1) levels of compost were similar to the high, 336-224, 112, commercial fertilizer rate (40.1 Mg ha-1).

In 2004, (in the second growing season after application), the low, moderate, and high compost rates increased corn silage yields by 58-75% compared to the no compost rate, however these three compost rates did not differ from each other. The two N rates evaluated (224 and 336 kg ha-1) did not differ. Only the moderate (90 Mg ha-1) compost rate was similar to the high, 336-224-112, commercial fertilizer rate.

In 2005, (in the third growing season after application), the low, moderate, and high compost rates increased corn silage yields by 39-69% compared to no compost application, however these yields were 17-42% lower than the high commercial fertilizer rate. The two N rates evaluated did not differ from each other. Based on the results of this study, the optimal compost rate was 90 Mg ha-1, which was equivalent to the high commercial fertilizer treatment in the first and second growing season, however by the third growing season it yielded less than the commercial fertilizer, which indicates that compost would need to be reapplied after two seasons of corn silage.

Compost Quality by Rate - Study II

Significant interactions were observed between year and compost quality, thus data are reported by year. In 2004, (the first growing season after application), corn silage yields in the HQC plots yielded 7-18% higher than plots treated with LQC. In 2004, the optimal compost rate was 45 Mg ha^{-1} for both LQC and HQC, which yielded 38% more corn silage than when compost was not applied. The optimal N rate for both LQC and HQC was 224 kg N ha^{-1}, which did not differ from 336 kg N ha^{-1}. The high commercial fertilizer rate (336-224-112) yielded 15% more corn silage than the LQC, but did not differ from the HQC in 2004.

In 2005, (the second season after application), the moderate and high rates of LQC yielded 9 and 15%, respectively more corn silage than the same rates of HQC, which is the reverse of the previous year. The HQC apparently had greater nutrient release rates compared to the LQC in the first season, however these nutrients were not available the second growing season. In 2005, the optimal N rate was 224 kg N ha^{-1}, which did not differ from 336 kg N ha^{-1}. In 2005, only the moderate compost rate (90 Mg ha-1) yielded equal corn silage to the high commercial fertilizer rate (336-224-112). When averaged across both years, compost qualities did not differ. The LQC averaged 43.4, 59.3, and 61.0 Mg ha-1 for no compost, low rate (45 Mg), and moderate rate (90 Mg ha^{-1}), respectively compared to the same rates of HQC which averaged 44.4, 59.6, and 62.7, respectively.

Table 1. Effect of dairy manure compost on corn silage during the 2003, 2004, and 2005 growing seasons, at Stephenville, TX.

	Growing Season		
Study I	2003	2004	2005
	Mg ha^{-1} @ 35% DM		
Compost Rate[a]			
135 Mg ha^{-1}	44.1 a[b]	65.2 a	56.4 a
90 Mg ha^{-1}	39.7 b	72.4 a	53.5 a
45 Mg ha^{-1}	39.0 b	67.6 a	46.5 b
0 Mg ha^{-1}	30.7 c	41.4 b	33.4 c
N rate			
224 kg N ha^{-1}	38.8 a	61.4 a	47.3 a
336 kg N ha^{-1}	38.0 a	62.0 a	48.4 a
Fertilizer[c]			
336-224-112	40.1 a	75.3 a	66.3 a
0-0-0	23.3 b	26.6 b	21.5 b

a Compost Applied in 2003
b Means within column and main effect followed by the same letter do not differ at the 0.05 significance level
c Commercial fertilizer applied kg N, P_2O_5, K_2O ha^{-1}

Table 2. Effect of compost quality on corn silage yields during the 2004 and 2005 growing seasons, at Stephenville, TX.

	Growing Season			
Study II	2004[a]		2005[b]	
	LQC[c]	HQC	LQC	HQC
Compost Rate	Mg ha^{-1} @ 35% DM			
135 Mg ha^{-1}	.	70.3 a[d]	.	52.4 a
90 Mg ha^{-1}	61.2 a B	72.4 a A[e]	60.7 a A	53.0 a B
45 Mg ha^{-1}	64.5 a B	69.6 a A	54.0 b A	49.5 b B
0 Mg ha^{-1}	47.1 b A	50.5 b A	39.6 c A	38.4 c A
N rate				
112 kg N ha^{-1}	.	63.0 b	.	45.0 b
224 kg N ha^{-1}	59.2 a B	67.6 a A	62.0 a A	50.0 a B
336 kg N ha^{-1}	56.0 a B	66.5 a A	61.9 a A	49.9 a B
Fertilizer[f]				
300-200-100	73.9 a	70.3 a	60.0 a	62.0 a
150-100-50	60.7 b	62.0 b	49.1 b	49.1 b
0-0-0	21.5 c	24.9 c	20.7 c	19.9 c

a First season after application
b Second season after application
c LQC, low quality compost; HQC, high quality compost
d means within column followed by the same lower case letter do not differ at the 0.05 significance level
e Means within year and row followed by the same upper case letter do not differ at the 0.05 significance level
f Commercial fertilizer applied kg N, P_2O_5, K_2O ha^{-1}

Dairy Manure Compost Improves Soil and Increases Tall Wheatgrass Yield

Twain J. Butler*and James P. Muir

Twain J. Butler, The Noble Foundation, 2510 Sam Noble Parkway Ardmore, OK 73401; James P. Muir, Texas Agricultural Experiment Station, A&M University Research & Extension Center, 1229 N. HW 281 Stephenville, TX 76401. *corresponding author (tjbutler@noble.org).

ABSTRACT

There is a need to identify alternative uses for composted manure applications. The objectives in this study were to 1) document the effect of composted dairy manure on soil agronomic characteristics, and 2) evaluate tall wheatgrass yield response to six rates of composted dairy manure. A field trial with a split-plot randomized complete block design and four replications was initiated on a Windthorst sandy loam soil (Udic Paleustalfs) in north-central Texas near Stephenville in September of 2001. Main plots were 1 by 7 m and received a single application of composted manure prior to planting Tall wheatgrass at 17 kg ha^{-1}. Composted dairy manure rates of 0, 11.2, 22.4, 44.8, 89.6, and 179.2 Mg dry matter (DM) ha^{-1}of a commercial source were applied. Subplots were 1 by 3.5 m and received annual split applications of 224 or 336 kg N ha^{-1} yr^{-1}. Application of compost improved or increased soil OM, soil pH, soil infiltration, soil P levels, and soil K levels, which, in turn increased tall wheatgrass DM yields (by 96% at the greatest rate compared to the control in 2002-03 and by 58% in 2003-04) yielding up to 9536 kg DM ha^{-1} in 2002-03 and 6097 kg DM ha^{-1} in 2003-04. Compost also increased the concentration of forage P (by 56 and 64%) and K (by 40 and 29%) at the greatest compost rate in 2002-03 and 2003-4, respectively. Tall wheatgrass responded to improved soil fertility, and could be utilized to grow forage of high nutritive value (up to 231 g CP kg^{-1} for the greatest compost rate in 2002-03, a 11.6% increase over the control, and a 9.5% increase, 175 g CP kg^{-1}, in 2003-04).

In areas of intensive agricultural and livestock production, soils with plant-available P exceeding the levels required for optimum crop yields have increased (Alley, 1991; Sims, 1992). For example, approximately 200,000 cattle in confined animal feeding operations generate an estimated 1.8 million metric tons yr^{-1} of manure in Erath county, TX (Brazos River Authority, 1993), which has led to an excess buildup of composted dairy manure. In order to avoid environmental problems related to P surface water runoff (Sharpley and Withers, 1994), there is a need to identify alternative uses for composted manure, especially where soil P levels are low.

The use of compost promotes soil aggregation, which improves soil structure and pH, increases water infiltration, and improves water holding capacity (Murray, 1981; USDA NRCS, 2004). The N-P-K percentages of finished compost are relatively low, but their benefit lies in the slow release of N and P in the soil so that plants can use them effectively before they are lost through leaching (Gershuny and Martin, 1992).

Forage P uptake from soils is highly variable and is a direct function of soil P content, soil physical properties, forage biomass, and forage P concentration, the latter often species-specific (Pierzynski and Logan, 1993). The application of dairy manure compost to soils can increase forage yields resulting in greater plant P concentrations and P yields, a phenomenon observed when compost is applied to summer annual dicots (Muir et al., 2001a), annual monocots (Muir et al., 2001b) or perennial grass (Sanderson and Jones, 1997). The efficacy of using composted manure on cool-season perennial grasses, however, has not been widely tested. Tall wheatgrass is a cool-season perennial grass that may have potential to provide forage of high nutritive value during the winter months, when the dominant warm-season grasses are dormant. However, the P fertility requirement and P removal rate for tall wheatgrass are unknown.

Two soil P testing methods, historically used to measure soil-P for both agronomic and regulatory purposes, ammonium acetate-ethylenediaminetetraacetic acid (NH_4OAc-EDTA) (Hons et al., 1990) and Mehlich III (Mehlich, 1984), can vary considerably in their estimation of plant-available soil-P (Butler et al., 2006). It is unclear which soil testing method should be utilized to predict available soil P. The objectives in this study were to 1) document the effect of composted dairy manure on selected Windthorst soil characteristics, 2) determine the appropriate soil test for measuring soil P in a Windthorst soil, and 3) evaluate tall wheatgrass yield response to six rates of composted dairy manure.

MATERIALS AND METHODS

A field study was initiated on a Windthorst sandy loam soil (Udic Paleustalf) in north-central Texas near Stephenville (N 32^o 15’, W 98^o 12’, altitude 395 m) in September of 2001. Initial soil test indicated pH= 5.1, 6 mg N kg^{-1}, 6 mg P kg^{-1} (NH_4OAc-EDTA extractant), and 205 mg K kg^{-1}. Treatments were arranged in a split-plot randomized complete block design with four replications, six main treatments (compost application rate) and two sub-treatments (N fertilizer rate). Main plots were 1 by 7 m and received a single application of composted manure prior to planting tall wheatgrass at 17 kg ha^{-1}. Composted manure rates of 0, 11.2, 22.4, 44.8, 89.6, and 179.2 Mg ha^{-1}of a commercial source of composted dairy manure from Producers Compost, Stephenville, TX, was incorporated to 15 cm depth using a roto-tiller. Compost analysis averaged 150 g kg^{-1} OM, 782 g kg^{-1} DM, 7.2 g kg^{-1} N, 3.9 g kg^{-1} P, and 15.7 g kg^{-1} K. Subplots were 1 by 3.5 m and received annual split applications of 224 or 336 kg N ha^{-1} yr^{-1}. Nitrogen (urea-ammonium sulfate blend) applications were surface-applied, with half applied in October and the remainder in February. Tall wheatgrass was sprayed with diclofop-methyl 2-[4-(2,4-dichlorophenoxy) phenoxy]propanoate at 0.84 kg ai ha^{-1} at the 5th-leaf stage to control annual ryegrass (*Lolium multiflorum* Lam.), since annual ryegrass will out-compete tall wheatgrass during establishment (Butler et al., 2005).

Plots were harvested with an Almaco small-plot harvester (Almaco, Nevada, IA) three times (December through May) during 2002-03 and 2003-04. Plots were not harvested during the establishment year, since tall wheatgrass is slow to establish. Sub-samples were used to determine forage DM yield by drying approximately 400 g of plant material in a forced-air oven at 55°C until weight loss ceased. Total aboveground DM production was estimated each year by totaling all yields from each year. Representative forage sub-samples from each sub-plot and year were ground through a Wiley mill (Thomas-

Wiley Co., Philadelphia, PA) equipped with 1-mm screen. Samples from each treatment and harvest were analyzed for N, P, K, and S. Nitrogen concentration was multiplied by 6.25 and reported as crude protein (CP) (Van Soest, 1994). Concentrations of these plant components are reported as season-long weighted averages for each subplot.

Approximately 15 soil cores were taken to a 15 cm depth for each subplot at the end of each growing season and composited by subplot to determine treatment differences. Soils were analyzed for pH using 1:2 ratio of soil to deionized water (Schofield and Taylor, 1995), NO_3-N by Cd reduction (Kenney and Nelson, 1982), and P, K, S, Na, Mg, and Ca based on two soil-extractant methods, acidified NH_4OAc-EDTA (TAMU) and Mehlich III (Mehlich, 1984; Hons et al., 1990). Elements in both extractants were measured using ICP-OES (Spectro Radial Modula ICP, Spectro Analytical Instruments, Marlborough, MA.). Soil OM concentration was determined by using the Loss-On-Ignition Method (LOI) (Nelson and Sommers, 1996). Soil samples were air dried and ground to <0.4 mm. A 1.00 to 3.00 g sample for each subplot was placed in a crucible and heated in an oven for 24 h at 105°C. Samples were then cooled in a dessicator and weighed to a tolerance of 0.1 mg. Samples were then placed in a muffle furnace for 16 h at 400°C, cooled, dessicated, and weighed. Infiltration rate of water into the soil was measured with a Turf-tec double ring infiltrometer obtained from Turf-tec International (Coral Springs, FL), by averaging three readings from each subplot at the end of each growing season. The infiltration rate was determined as the amount of water per surface area and time unit which penetrated the soil (Bouwer, 1986).

Data were subjected to analyses of variance using PROC GLM (SAS, 1999) with differences less than P=0.05 reported as significant. Means, where appropriate, were separated using Fisher's Protected LSD test at P=0.05 level of significance. Differences in rainfall distribution (but not total) among growing seasons (September-June) were apparent (Figure 1). Precipitation in the 2002-03 season totaled 782 mm and the 2003-04 season totaled 787 mm, however there was poor distribution of moisture in the early months of 2003-04.

RESULTS AND DISCUSSION

Soil Nutrient Status

Year, year X compost rate, year X N rate, and year X compost X N rate interactions were not significant (Table 1), therefore data are pooled across years for soil pH, N, P, K, OM, and infiltration. Soil S, Na, Mg, and Ca, and did not differ among year, compost level, or extraction method (data not shown).

Soil OM

Soil OM increased as composted dairy manure rates increased (Table 4). Soil OM in the untreated plots averaged 13 g kg^{-1} compared to 20 g kg^{-1} in the plots with the greatest compost rate. The addition of compost OM to the soil can increase CEC from 20 to 70% of the original CEC (Mott, 1974; Halvin et al., 1999). Not all composted manures increase soil OM or organic carbon (Helton, 2004), primarily because some composts have low levels of OM since they originate from drylot scrapings high in soil content.

Soil pH

Soil pH increased as composted dairy manure rates increased (Table 4). Soil pH in the untreated plots averaged 4.5 compared to 7.0 at the greatest compost rate (179.2 Mg ha^{-1}), and increased an average 0.5 unit as compost rate doubled in magnitude from 11.2 to 179.2 Mg ha^{-1}. Seedling establishment and soil pH were also increased with applications of compost elsewhere (Murray, 1981). The increase in soil pH can be partially attributed to the increase in soil OM and the high pH of the compost itself, a result of a high concentration of calcareous soil particles in the dairy compost generated by north Texas dairies (Helton, 2004). Soil pH decreased as N rate increased from 224 to 336 kg ha^{-1}, which was expected in the top 15 cm of soil (Haby et al., 1999). Dairy manure and its compost have the potential to raise pH of acidic soils receiving N fertilizer (Sanderson and Jones, 1997; Helton, 2004) or mitigate the acidification of soils receiving soil-acidifying forms of N fertilizer.

Soil Infiltration

Soil infiltration with water increased linearly (Table 4) with increasing rates of compost dairy manure. Infiltration increased by 100%, 242%, 292%, 408%, and 550% for 11.2, 22.4, 44.8, 89.6, and 179.2 Mg ha^{-1}, respectively, when compared to the untreated control. Increase in infiltration can be attributed to increased OM. Improvements in soil moisture retention due to the increase in soil OM have been reported by others (Hoitink and Fahy, 1986; Boehm et al., 1993).

Soil NO_3-N

Dairy manure compost had little effect on soil N levels, although there was a numeric trend for greater compost manure rates having lower soil N levels, which could be related to greater forage DM yields in those plots. Composting dairy manure tends to lower NH_4–N levels vis-à-vis the original manure, but NO_3-N tends to be more stable in compost; in at least one study looking at both dairy manure and its compost, however, NH_4–N concentrations were more stable in the soil than was NO_3-N (Helton, 2004). Soil N level with 336 kg ha^{-1} was 41% greater than at the 224 kg ha^{-1} rate.

Soil-P

Soil P levels increased with both soil extractants, as composted dairy manure increased (Table 4); however, soil extractants differed in their estimate of plant-available P. At very low soil P levels, the Mehlich extractant soil P was approximately 1.5 times greater than the EDTA extractant P, but there were no differences between extractants when available soil P was very high with the heaviest compost rate (Table 2). The highest compost rate (179.2 Mg ha^{-1}) which yielded 124 mg P kg^{-1} soil, did not exceed the maximum soil P threshold of 200 mg P kg^{-1} allowed by environmental regulatory agencies in Texas (Texas Administrative Code, 1997), indicating that these low-P soils can incorporate very high rates of compost before this limit is reached. In contrast, Helton (2004), in a perennial warm-season grass study in which he surface-applied 57 Mg compost ha^{-1} to a similar Windthorst soil with a control plot containing 22 mg P kg^{-1} soil, measured plant-available P well in excess of the 200 mg P kg^{-1} soil limit (EDTA) in the top 15 cm. The main difference may have been that Helton (2004) did not incorporate compost to a 15-cm depth as was done in the present study.

Fertilizer N rate had little effect on plant-available soil P. The Texas Cooperative Extension Soil, Water and Forage Testing Laboratory adopted the statewide use of the Mehlich III method in Jan. 2004, following the determination that the NH_4OAc-EDTA method dissolved non-plant available apatite in certain calcareous soils (personal communication, T. Provin, 2004).

Soil-K

Soil K levels also increased as compost rate increased (Table 4), a phenomenon observed in other compost studies (Schlegel, 1992; Helton, 2004); however, the extractants differed in their estimation of plant-available K. The EDTA extractant measured greater levels of plant-available K compared to the Mehlich extractant, which is the reverse trend of plant-available soil P. Mehlich III uses a 5-minute shaking time compared to 45 minutes for the EDTA, resulting in a more complete release of soil-bound K (Mehlich, A. 1984; Hons et al., 1990) which tends to be more weakly bound to soil particles compared to P in its HPO_2 and H_2PO_4 forms (Pierzynski et al., 2005). Soil K levels were adequate even in the untreated plots; therefore it is unlikely that the increased levels of K influenced crop yield. Nitrogen fertilizer rate had little effect on available soil K.

Tall Wheatgrass

Year and year X compost interactions were apparent for DM yield, N removal, P removal, and K removal (Table 1), therefore data are reported by year. Sulfur concentrations of tall wheatgrass tissue and S levels of soil did not differ among treatments, so S removal rates are not reported.

Forage DM Yield

In both growing seasons, DM yield increased with application of composted dairy manure (Table 3; Table 4). Forage DM yield was lowest where compost was not applied (4857 kg ha^{-1} for 2002-03 and 3858 for 2003-04) and increased by 32, 44, 64, 85, and 96% with 11.2, 22.4, 44.8, 89.6, and 179.2 Mg compost ha^{-1}, respectively in 2002-03 and by 31, 33, 37, 42, and 58% in 2003-04 (Table 4). The greatest DM yields occurred with the highest compost rate (179.2 Mg ha^{-1}) with yields of 9536 and 6097 kg ha^{-1} in each growing season respectively, which is similar to the maximum yields reported for other cool-season grasses. Reported yearly DM yields of timothy (*Phleum pretense* L.), orchardgrass (*Dactylis glomerata* L.), reed canarygrass (*Phalaris arundinaceae* L.), smooth brome (*Bromus inermis* Leyss.), and tall fescue (*Festuca arundicaea Schreb*.) averaged 9770, 7970, 9707, 7881, and 9968 kg DM ha^{-1}, respectively (Cherney and Cherney, 2005). Butler et al., (2006) reported DM yields of annual ryegrass (*Lolium multiflorum* Lam.) under the same environment as this study, which ranged from 4550 to 10510 kg DM ha^{-1} when fertilizer rates ranged from 0 to 40 kg P ha^{-1}. Forage yields did not differ between the N rates in either year, indicating that N rates lower than 224 kg ha^{-1} may suffice to attain maximum forage yields. These data illustrate that tall wheatgrass responds to application of composted manure, which improves soil fertility, especially soil P, and that tall wheatgrass has forage potential for the region.

Crude Protein and N removal.

Forage CP concentration (Table 3) was greater in 2002-03 (ranging from 207 to 231 g CP kg^{-1}) compared to 2003-04 (158 to 175 g CP kg^{-1}); however, all CP values would be considered adequate for most livestock classes (Ball et al., 2002). These relatively high values are greater than those reported for other cool-season perennial grasses. Cherney and Cherney (2005) reported CP values for timothy, orchardgrass, reed canarygrass, smooth brome, and tall fescue that averaged 105, 122, 123, 132, and 110 g kg^{-1}, respectively. Butler et al. (2006) reported CP values ranging from 202 to 248 g kg^{-1} for annual ryegrass. Crude protein was greatest at the two highest compost rates (89.6 and 179.2 mg ha^{-1}) in 2002-03 but did not differ between compost rates in the 2003-04 growing season (Table 4). Crude protein values did not differ between the two N rates in 2002-03. However, CP was 10% greater with the 336 kg N ha^{-1} rate in 2003-04, but this is probably not of biological importance.

The amount of N removed, which is a function of N concentration and DM yield, followed a similar trend to that of yield. As compost rate increased, the amount of N removed also increased up to 119%, ranging from 161 to 353 kg N ha^{-1} in 2002-03 and 98 to 169 kg N ha^{-1} in 2003-04 (72% increase) (Table 4). Nitrogen rate did not affect N removal in 2002-03, however the 336 kg N ha-1 rate removed 17% more N due to the greater concentration of N in forage that season. These data illustrate that the amount of nutrient removal is closely related to DM yield, and, as yield increases, the nutrient removal rate also will increase.

Phosphorus concentration and P removal.
Forage P concentrations (Table 3) in 2002-03 ranged from 1.8 to 2.8 g P kg^{-1}, greater than in 2003-04 (ranging from 1.4 to 2.3 g P kg^{-1}). These values are similar to those reported for grasses other than wheatgrass. Cherney and Cherney (2005) reported that P concentrations of timothy, orchardgrass, reed canarygrass, smooth brome, and tall fescue averaged 2.35, 2.87, 3.20, 3.08, and 2.78 g K kg^{-1}, respectively and ranged from 2.41 to 3.32 g P kg^{-1} depending on the year. Butler et al. (2006) reported that annual ryegrass, when grown in the same environment as this study and fertilized with 0 to 48 kg P ha^{-1} yr^{-1}, had P concentrations from 1.9 to 4.0 g P kg^{-1}. These values are slightly greater than the values measured in the present study with tall wheatgrass. Tall wheatgrass P concentrations increased 6 to 56% in 2002-03 and 14 to 64% in 2003-04, from the lowest to highest compost rate (Table 4).

The amount of P removed ranged from 5.4 to 26.7 kg P ha^{-1} and increased with compost rate (Table 3), primarily due to greater forage yields and P concentrations resulting from compost application. Butler et al. (2006) also reported that annual ryegrass removed from 8 to 40 kg P ha^{-1}, depending on the P fertilizer rate. In the 2002-03 growing season, removal of P increased by 40 to 206% as compost rate increased and by 50 to 159% in 2003-04 (Table 4). However, the cumulative P recovery rates when combining P removal for both growing seasons were 0.141, 0.106, 0.084, 0.058, 0.038 for composted manure rates of 11.2, 22.4, 44.8, 89.6, 179.2 Mg ha^{-1}, respectively. Fertilizer N rate had little effect on P concentration or the amount of P removed from the soil. These data indicate that tall wheatgrass could potentially be utilized on high P soils to remove excess P.

Potassium Concentration and K removal

Forage K concentration followed a similar trend as P, ranging from 19.7 to 27.5 g kg^{-1} in 2002-03 and from 18.9 to 24.4 g kg^{-1} in 2003-04. Cherney and Cherney (2005) reported K concentrations of timothy, orchardgrass, reed canarygrass, smooth brome, and tall fescue averaging 14.5, 15.9, 16.3, 17.8, and 15.1 g kg^{-1}, respectively and varying from 14.1 to 21.4 g K kg^{-1}, depending on the year. In the present study, K concentration increased by 9 to 40% in 2002-03 and 6 to 29% in 2003-04 from the lowest to highest rate of compost application. The amount of K removed ranged from 96 to 262 kg K ha^{-1} in 2002-03 and 73 to 149 kg K ha^{-1}. Cherney and Cherney (2005) also reported that timothy, orchardgrass, reed canarygrass, smooth brome, and tall fescue removed from 100 to 159 kg K ha^{-1} from the soil. Several cool-season grasses have been reported to be luxury consumers of K (Cherney et al., 1998). Tall wheatgrass could also be considered a luxury consumer since for K concentrations increased as soil K increased with compost rates despite adequate soil K the untreated plots. Nitrogen fertilizer had little effect on K concentrations or the amount of K removed from the soil.

CONCLUSIONS

Application of dairy manure compost increased soil OM, soil pH, soil infiltration, soil P levels, and soil K levels, which, in turn, increased tall wheatgrass DM yields and P and K concentrations in the forage. Tall wheatgrass is similar to other cool-season grasses in that it will respond to improved soil fertility, especially soil P, and could be utilized to provide forage of relatively high nutritive value with similar DM yields and P removal rates to that of other cool-season grasses.

TABLES & FIGURES

Table 1. Analysis of variance for soil and forage parameters of Jose tall wheatgrass in the 2002-04 growing seasons at Stephenville, TX.

	Soil Parameters										
					P		K		S		
Source	pH	OM	Infiltration	NO_3-N	EDTA	Mehlich	EDTA	Mehlich	EDTA	Mehlich	EC
Year	NS†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Compost	***	***	***	***	***	***	***	***	NS	NS	NS
Year*Compost	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N rate	***	NS	NS	***	NS	NS	NS	NS	NS	NS	NS
Year* N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Compost*N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year*Compost*N	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

	Forage Parameters								
	DM yield	N %	N removed kg ha^{-1}	P %	P removed kg ha^{-1}	K %	K removed kg ha^{-1}	S %	S removed kg ha^{-1}
Source									
Year	***	***	***	***	***	***	***	***	***
Compost	***	NS	***	***	***	***	***	**	***
Year*Compost	***	NS	***	NS	***	NS	*	NS	*
N rate	NS	**	***	NS	*	NS	*	NS	*
Year* N	NS	NS	NS	NS	NS	NS	NS	NS	NS
Compost*N	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year*Compost*N	NS	NS	NS	NS	NS	NS	NS	NS	NS

†NS, not significant; *, **, ***, 0.05, 0.01, and 0.001 level of significance, respectively; OM, organic matter; DM. dry matter; EDTA, ethylenediaminetetraacetic acid; EC, electric conductivity

Table 2. Response of soil parameters (pH, NO3-N, P, K, OM†, and infiltration) to dairy manure compost averaged over the 2002-03 and 2003-04 growing seasons in Stephenville, TX.

	Soil							
	OM	Soil	Infiltration	NO_3-N	P (mg kg^{-1})		K (mg kg^{-1})	
Compost Rate	%	pH	mm	mg kg^{-1}	EDTA	Mehlich III	EDTA	Mehlich III
0 Mg ha^{-1}	1.3	4.5	12	43	8	21	220	200
11.2 Mg ha^{-1}	1.4	5.0	24	39	11	26	265	245
22.4 Mg ha^{-1}	1.5	5.2	41	38	13	30	270	242
44.8 Mg ha^{-1}	1.6	5.9	47	30	20	40	294	269
89.6 Mg ha^{-1}	1.9	6.5	61	29	58	79	338	314
179.2 Mg ha^{-1}	2.0	7.0	78	31	124	122	400	368
LSD	0.2	0.3	4	NS	17	13	45	45
N Rate								
224 kg ha^{-1}	1.7	5.7	43	29	38	53	300	274
336 kg ha^{-1}	1.7	5.5	44	41	39	54	295	272
LSD	N.S.	0.2	N.S.	9.0	N.S.	N.S.	N.S.	N.S.

†OM, organic matter; EDTA, ethylenediaminetetraacetic acid; NS, not significant.

Table 3. Response of Jose tall wheatgrass to compost and nitrogen treatments at Stephenville, TX in the 2002-03 and 2003-04 growing seasons.

			2002-03				
Compost Rate	kg DM† ha^{-1}	CP g kg^{-1}	N removal kg N ha^{-1}	P g kg^{-1}	P removal kg P ha^{-1}	K g kg^{-1}	K removal kg K ha^{-1}
0 Mg ha^{-1}	4857	207	161	1.8	8.7	19.7	96
11.2 Mg ha^{-1}	6400	203	208	1.9	12.2	21.4	137
22.4 Mg ha^{-1}	7003	208	233	2.1	14.7	23.0	161
44.8 Mg ha^{-1}	7970	218	278	2.3	18.3	24.4	194
89.6 Mg ha^{-1}	8989	223	321	2.5	22.5	25.8	232
179.2 Mg ha^{-1}	9536	231	353	2.8	26.7	27.5	262
LSD	1475	10	46	0.2	3.3	2.1	33
N Rate							
224 kg ha^{-1}	7379	220	260	2.3	17.0	23.6	174
336 kg ha^{-1}	7540	217	262	2.2	16.6	23.6	178
LSD	N.S.	N.S.	N.S.	N.S	N.S.	N.S.	N.S.
			2003-04				
Compost Rate	kg DM† ha^{-1}	CP g kg^{-1}	N removal kg N ha^{-1}	P g kg^{-1}	P removal kg P ha^{-1}	K g kg^{-1}	K removal kg K ha^{-1}
0 Mg ha^{-1}	3858	158	98	1.4	5.4	18.9	73
11.2 Mg ha^{-1}	5055	165	133	1.6	8.1	20.1	102
22.4 Mg ha^{-1}	5126	169	139	1.7	8.7	21.2	109
44.8 Mg ha^{-1}	5301	170	144	2.0	10.6	21.4	113
89.6 Mg ha^{-1}	5486	175	154	2.2	12.1	24.3	133
179.2 Mg ha^{-1}	6097	173	169	2.3	14.0	24.4	149
LSD	563	N.S	14	0.1	1.1	1.2	18
N Rate							
224 kg ha^{-1}	4956	160	127	1.8	8.9	22.0	109
336 kg ha^{-1}	5303	176	148	1.8	9.5	22.1	117
LSD	N.S.	8	9	N.S.	N.S	N.S.	N.S.

†DM, dry matter; CP, crude protein.

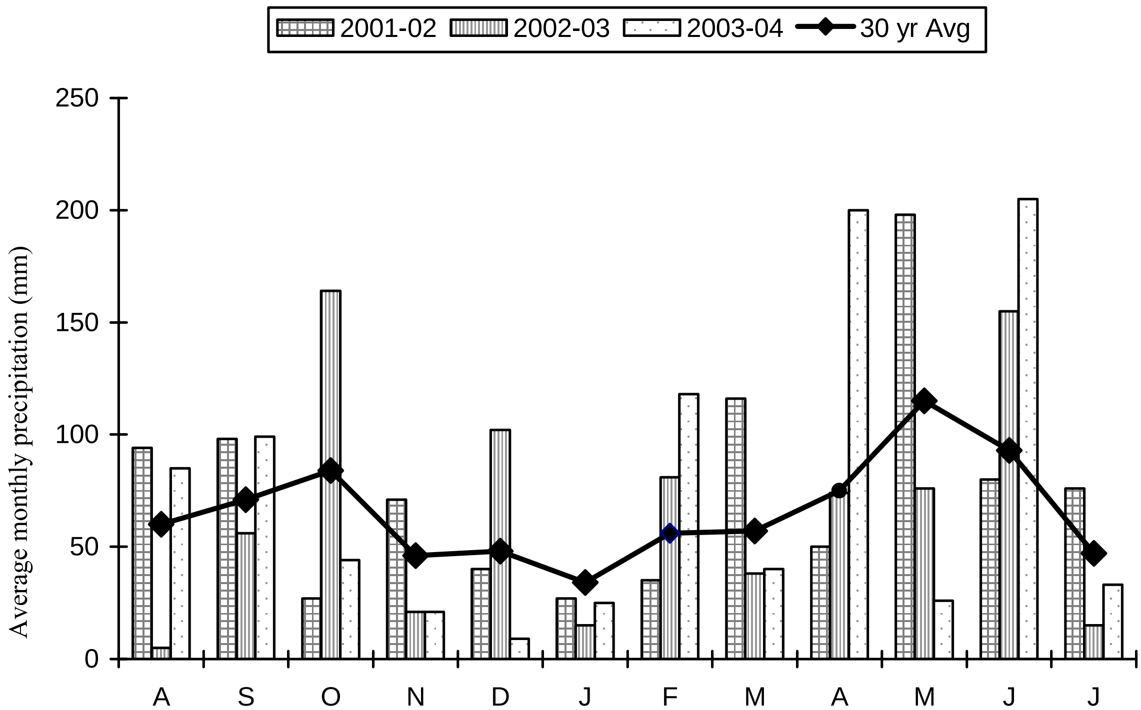


Figure 1. Monthly precipitation from August to July during three years and 30-yr average trend line at Stephenville, TX, USA.

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Efficacy of Using Dairy Manure Compost as Erosion Control and Revegetation Material.

Saqib Mukhtar, Mark L. McFarland Cecilia A. Gerngross, Franklin J. Mazac

INTRODUCTION

Several watersheds with large and concentrated animal feeding operations (CAFOs) in the USA are faced with a challenge to either reduce manure application rates on agricultural soils that test high in phosphorous (P) or find alternatives to manure utilization by row crops and pastures. The Bosque and Leon River watersheds in central Texas are home to nearly 100,000 lactating dairy cows that reside on 165 farms. Most of these cows are housed either on openlots or hybrid systems of openlots and freestall barns. Manure from openlots is scraped and stock piled while liquid waste (manure, process generated wastewater from flushed freestalls, milking parlors and paved alleyways in openlots, and any runoff water) is stored in waste storage or treatment structures (lagoons). In general, a majority of the dairy manure from these operations is handled as solid manure. Traditionally, solid manure and liquid waste have been spread and irrigated, respectively to waste application fields (WAF) as nutrients for crops and pastures, and to meet the plant water requirements. The North Bosque River (NBR) basin has the highest concentration of dairy cows in the area. Water quality studies in the watershed indicated that P was the limiting nutrient in this basin and dairy WAFs and municipal waste treatment plants were considered major non-point and point sources of P to the NBR, respectively (McFarland and Hauck, 1999a, 1999b). In 1998, segments 1226 and 1255 of the NBR and Upper NBR, respectively were deemed "impaired segments" on the State of Texas Clean Water Act Section 303(d) under water quality standards related to nutrients and aquatic plant growth (TNRCC, 1998).These findings led to the US Environmental Protection Agency’s approval for the two Total Maximum Daily Loads (TMDLs) for P in the NBR (TNRCC, 2001). In December 2002, the Texas Commission on Environmental Quality (TCEQ, previously known as the Texas Natural Resource Conservation Commission or TNRCC) approved the implementation plan for the two TMDLs. The goal of these TMDLs was to achieve a reduction of total annual loading and annual average concentrations of soluble reactive P (SRP) by approximately 50%. The Bosque River Advisory Committee, a group of scientists, engineers and other stakeholders, expects that both point and nonpoint sources will have to make significant reductions in their P contributions to achieve this goal.

As a result of poor water quality conditions in the NBR watershed, the TCEQ rules implemented in 1999 required that every new or expanding CAFO in the watershed must remove 100% of the collectible manure produced in the facility. Manure should be disposed of beneficially outside the watershed (landfills), delivered to a composting facility or applied as fertilizer to WAFs that have not received manure previously and have less than 200 ppm of extractible P in the top six inches of soil (TNRCC, 1999). Consequently, a voluntary program called the “Compost Program” was initiated by the TCEQ and the Texas State Soil and Water Conservation Board (TSSWCB) with a goal to remove nearly 50% of the manure generated by the CAFOs in the NBR watershed as an ‘efficient way’ of dairies to meet these new rules (TCEQ, 2003). In 2000, as part of this program, the TSSWCB launched the Dairy Manure Export Support (DMES) project that provided financial support to haul surplus manure from dairies in the NBR watershed to the TCEQ permitted composting facilities in the NBR watershed. These composting facilities provide dairies an alternative to direct application of manures on soil testing high for P in the watershed. The TCEQ portion of the program strived to create a sustainable market for compost from dairy manure.

Recently published works by Persyn et al. (2004) and Risse and Faucette (2003) cite use of compost from various organic materials including animal manure for erosion control and revegetation of highway construction sites. Compost from cattle feedlot, dairy and poultry manure mixed with woodchips, cotton burs and yard trimmings has been utilized by many state transportation departments for erosion control of road rights-of-way and to establish vegetation on severely eroded soils (Block, 1999, 2000; Mitchell 1997). Departments of transportation from several states have developed compost use specifications (USEPA, 2003) for construction related projects. Texas Department of Transportation (TxDOT) accepts organic composts including dairy manure compost (DMC) for use in compost manufactured top soil (CMT), in erosion control compost (ECC), as general use compost (GUC) and compost in the form of filter berms for erosion and sedimentation control. For the TxDOT contracts, the CMT should consist of 75% topsoil blended with 25% compost on a volume basis and for ECC, 50% untreated woodchips are blended with 50% compost by volume (Special Specifications 1058 for compost and 1059 for compost/mulch filter berm, TxDOT, 2002). The TxDOT specifies the use of ECC to be limited to slopes of 3:1 or flatter allowing an application of a 2” uniform layer of compost and woodchips blend. These specifications provide an opportunity to remove DMC (hence dairy manure) out of the NBR and use it on the TxDOT projects, as an alternative to manure utilization on traditional crop and pasture land in the watershed. Large quantities of DMC will be used as CMT or ECC to vegetate and protect slopes such as the road rights-of-way. Little information is available on physicochemical quality of runoff from these CMT and ECC treated slopes using blends of DMC and woodchips.

OBJECTIVE

The objective of this study was to examine the efficacy of using composted dairy manure for stabilization and revegetation of steep slopes. Results of runoff and its physicochemical constituents from filed plots amended with DMC, DMC/Woodchips blend, and commercial fertilizer (CF) and subjected to simulated rainfall are presented in this paper.

MATERIALS AND METHODS

Experimental plots and treatment set-up

Twelve plots, each 1x 2m were established on an embankment with 3:1 side slope and constructed to mimic a road right-of-way (Li et al., 2003) at the Riverside campus of the Texas A&M University near College Station. The embankment soil was clayey with an average pH of 8.13 from the 0-15-cm (0-6”) depth and devoid of vegetation. Average sand, silt and clay contents from the 0-15 cm depth were 26%, 27%, and 47%, respectively. Each plot was isolated from overland flow using 15-cm (6”) metal borders installed 10-cm above and 5-cm below the ground level. At the downstream end of each plot, a parabolic shaped gutter made from a 10-cm PVC pipe, spliced in half longitudinally, was installed to convey plot runoff to plastic buckets. Four treatments namely, erosion control compost {ECC, per TxDOT (2002) specifications}, compost manufactured topsoil {CMT, per TxDOT (2002) specifications}, agronomic rate compost (ARC) and commercial fertilizer (CF) were replicated (blocks) three times and randomly assigned to 12 plots, in a ‘randomized block’ design (Figure1). For each CMT treatment plot, a 2.5-cm (1") layer of DMC was incorporated in to 8-cm (3") of the topsoil using a heavy duty garden hoe. For each ECC treatment plot, a blend of 50% DMC and 50% woodchips by volume was applied as a 5-cm (2") thick layer of erosion control blanket on top of the existing undisturbed soil. Dairy manure compost at a rate of 39.5 t/ha (16 t/ac) was applied on undisturbed soil of each ARC treatment. Each CF treatment plot received mineral fertilizer at the rate of 112kg/ha (100 lb/ac) for nitrogen (N), 49 kg/ha (44 lb/ac as P or 100 lb/ac as P_2O_5) for phosphorus (P), and 83 kg/ha (83 lb/ac as K or 100 lb/ac as K_2O) potassium (K), respectively. Table 1 shows application rates (kg/ha) of N, P, and K for each treatment.

Rainfall simulation and surface runoff sampling

Two rainfall simulators (Figure 2), similar to those used in the National Phosphorous Research Project (Sharpley and Klienman, 2003) and described by Humphry et al. (2002) were used simultaneously to conduct rainfall simulation and runoff sampling experiments on experimental plots. Each simulator was designed and equipped with one HH-SS50WSQ nozzle (Spraying Systems Co., Wheaton, IL).

The simulator frame, a 2.8 m (L) by 2.3 m (W) by 3 m (H) aluminum structure, was fitted with plastic tarps (walls) to minimize wind interference during the rainfall event. Each simulator was leveled on its telescopic legs (pegs) and installed so that the nozzle was centered above the plot. A 1,025-gal capacity water tank and de-ionizing system were used to supply water with a pH of 5.6 and an electrical conductivity of 0.015 µS m^{-1}. Prior to rainfall simulation, volumetric soil moisture was determined at the 0-5-cm (0-2") depth from each treatment plot using a capacitance sensor (Theta Probe, Delta-T Devices, Cambridge, UK) at five locations within a plot (Table 1).

On each plot, simulated rainfall of 92 mm h^{-1} (3.6" h^{-1}) average intensity (25-yr return frequency of a 1-h storm at the experimental site) from an average height of 3.22 m (10.6 ft) above plot surface was applied to cover a 4-m^2 footprint, which ensured complete coverage of the 1 x2 m plot. Rainfall with this intensity was applied on each plot until 30-min of runoff was obtained.

Table 1. Nitrogen, P and K application rate (kg/ha) and moisture content at 0-5 cm depth of treatment plots.

Treatment	**N,** kg/ha (lb/ac)	**P,** kg/ha (lb/ac)	**K,** kg/ha (lb/ac)	**Moisture** % (v/v), n=15
CMT	1,635 (1,459)	545 (486)	3,493 (3,116)	21.35 ±4.07*
ECC	2,976 (2,665)	903 (806)	5,985 (5,340)	14.37 ±2.75
ARC	199 (178)	66 (59)	425 (379)	27.44 ±5.18
CF	112 (100)	49 (44)	93 (83)	27.21 ±3.6

*Standard deviation

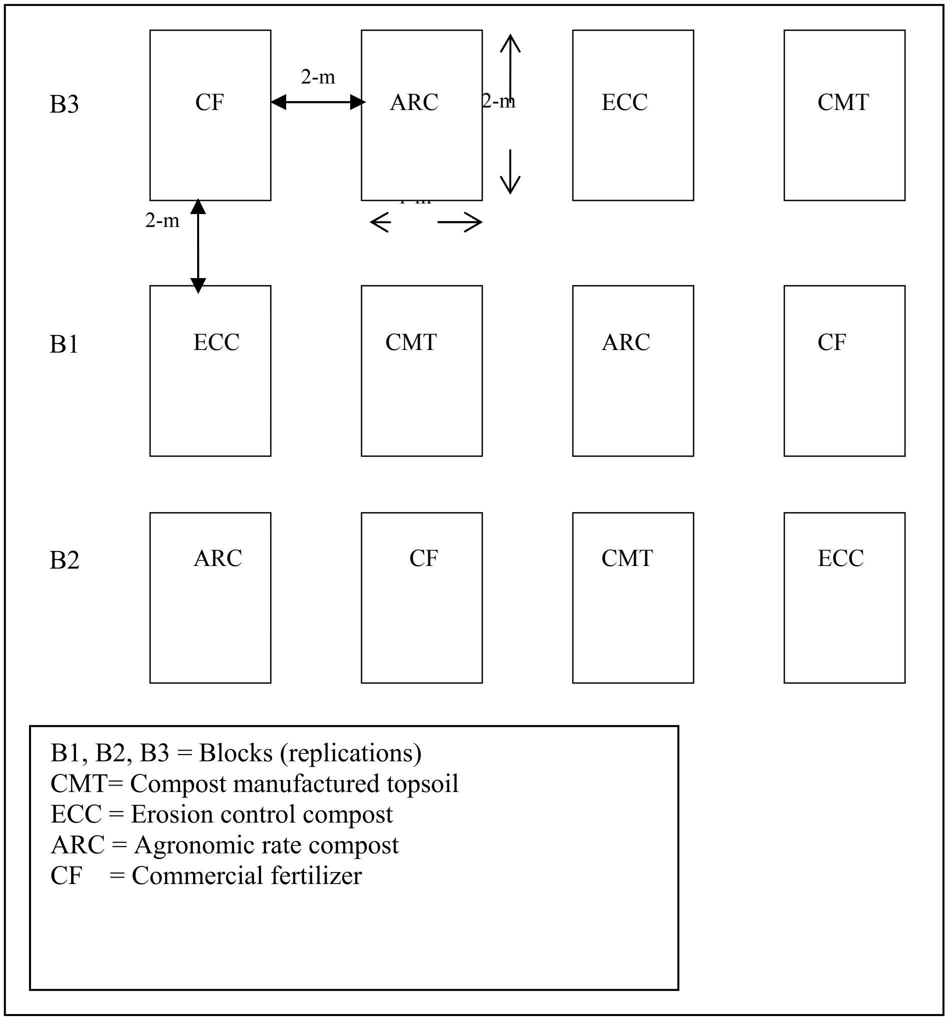

Figure 1. Experimental plots and treatment set-up (dimensions are not to scale)

Figure 2. Two rainfall simulators wrapped in plastic tarps, and a nozzle in use at the runoff plots.

After the start of rainfall on a plot, the time to initiate runoff (time difference between start of rainfall and beginning of overland flow) was recorded and the first liter of this runoff (the 'first flush') was collected directly in a plastic bottle. The remaining runoff was conveyed from PVC gutters to a plastic bucket and pumped to 26-L plastic containers. Total mass and volume of 30 min of overland flow from each plot was measured by weighing the containers. After weighing, the contents of all containers were emptied in a 136-L plastic drum, thoroughly agitated to resuspend solids and a representative 'sub sample' was collected in a plastic bottle. The entire procedure for rainfall simulation and runoff sampling was repeated for 12 plots.

Soil, compost, woodchips, and runoff analysis procedure

All soil, compost, compost/woodchips blend and runoff samples were analyzed for various physicochemical properties at the Soil, Water, and Forage Testing Laboratory, Department of Soil and Crop Sciences at the Texas A&M University. Additionally, runoff samples were also analyzed for total solids (TS) and total suspended solids (TSS) at Inter-Mountain Laboratories Inc., in College Station. Three composite soil samples were taken with a hand probe from 0 to 15-cm depths at the experimental site near bordered plots. Each core was divided into 0-5cm and 5-15 cm in depth. The soil samples were analyzed for extractable soil P (Hons et al., 1990) through Inductively Coupled Plasma Optical Emission Spectroscopy (ICP) and NO_3-N was analyzed using a modified version of Keeney and Nelson (1982) where 1M KCl was substituted for 2M KCL.

Three representative samples of dairy manure compost (DMC) and two representative samples of DMC/woodchips blend were also collected. These samples were pulverized to finer than 100 mesh, to decrease heterogeneity and 0.5 g of the pulverized sample was digested as received with sulfuric acid/selenium/lithium sulfate Kjeldahl digest (Parkinson and Allen, 1975). Total Kjeldahl Nitrogen (TKN) was determined colorimetrically using a Technicon Auto Analyzer II (Technicon Instruments Corporation, Tarrytown, NY). Total elemental P and K were analyzed using ICP.

A portion of 'first flush' and 'rest of the runoff' samples was filtered through a 0.45-micron pore-diameter filter. The unfiltered samples were blended and digested as received and analyzed for TKN, P and K using the same procedure used for the compost and woodchips samples. The filtered samples were analyzed for total dissolved P DP), dissolved K (DK), Nitrate-nitrogen (NO_3-N) and ammonium –nitrogen (NH_4-N) using ICP.

Total solids and TSS were determined from the unfiltered samples of the first flush and the rest of the runoff using Standard Methods (APHA, 1995) 2540B and 2540D, respectively. For TS, a sample was well mixed and dried to a constant weight at 105 ^{O}C. The dried sample contents represented TS. For the TSS determination, a well-mixed sample was filtered through a glass-fiber filter. The residue retained on the filter was dried to a constant weight at 105 ^{O}C. The dried sample contents represented TSS. For liquid samples, pH was measured directly using a probe and for solid samples it was determined from 2:1 water to solid paste.

Statistical analysis

A complete randomized block design was used to compare treatment effects on various physicochemical parameters in this rainfall-runoff study. Fisher's least significant difference

(LSD) method was used to compare treatment means. The data were analyzed using ANOVA procedure on Stat View software by SAS Inc.

RESULTS AND DISCUSSION

After initiation of the runoff from a simulated rainfall event, water leaked out of the borders from one experimental plot assigned to the CMT treatment. Therefore, only two replications for this treatment were included in the statistical analysis for all parameters related to runoff sampling and analysis.

Time to initiate runoff

The total time to initiate runoff, total mass of runoff, TSS and TS, and their respective standard deviations for each treatment are plotted in Figure 3. The average time to initiate runoff from the CMT plots was significantly higher ($p \leq 0.05$) than that from all other treatment plots while it was statistically similar among the ECC, ARC and CF treatment plots. The average time to initiate runoff from the ECC plots was the shortest (3.66 min) of all treatments. In fact, as compared to the ECC plots, it took more than twice as much time for the runoff to begin from the CMT (7.7 min) plots.

For the ECC plots, this may have been due to a lack of moisture absorption by the woodchips in the blanket (compost and woodchip mixture) as it was observed that at the beginning of the rainfall, this blanket was somewhat hydrophobic. On the other hand, the tillage induced conditions including reduced soil moisture (Table 1), increased surface roughness and reduced crusting and sealing may have resulted in increased infiltration of the CMT treatment plots, thereby delaying runoff time. Significantly higher initial infiltration from tillage as compared to no-till surface has been observed by Mukhtar et al. (1985).

Total runoff, TS and TSS

The total runoff mass from within each treatment varied highly (Figure 3) and was statistically similar among all treatments. Overall, average total runoff mass from CF was higher than and from ECC was lower than all other treatments.

The CMT plots had the second lowest total runoff mass followed by ARC and CF treatment plots. Although runoff initiated most quickly from the ECC plots, these plots contributed the smallest mass (and volume) of runoff. This in part was due to the fact that ECC plots had the lowest TS and TSS in runoff than those from all other treatment plots (Figure 3). The reduction in TS and TSS (hence erosion) from the ECC plots was due to the reduced raindrop impact. Because the soil surface was covered by the erosion control blanket, this resulted in less detachment and transport of sediment. Additionally, absorption of moisture by dairy manure compost in the ECC and CMT plots may also have contributed to relatively smaller amount of total runoff. Overall, TS amount from the CF treatment plots was significantly higher ($p \leq 0.05$) than that from all other treatments. The TSS amount from the CF plots was significantly higher than that from the ECC plots and higher but statistically similar to that from the rest of the treatments. Lower runoff rates and volumes and reduced soil erosion from organic compost treated soils compared to control treatments have been reported in several studies (Demars et al., 2000, Storey et al., 1996, Risse and Faucette, 2003 and Persyn et al., 2004). Figure 3 also shows that nearly all (2.38kg of 2.46kg) the solids in the runoff from the CMT plots were characterized as suspended solids while TSS amounts in the runoff from all other treatment plots were between 50% and 75% of TS. Additionally, little soil could be detected in the runoff samples from the ECC treatment plots.

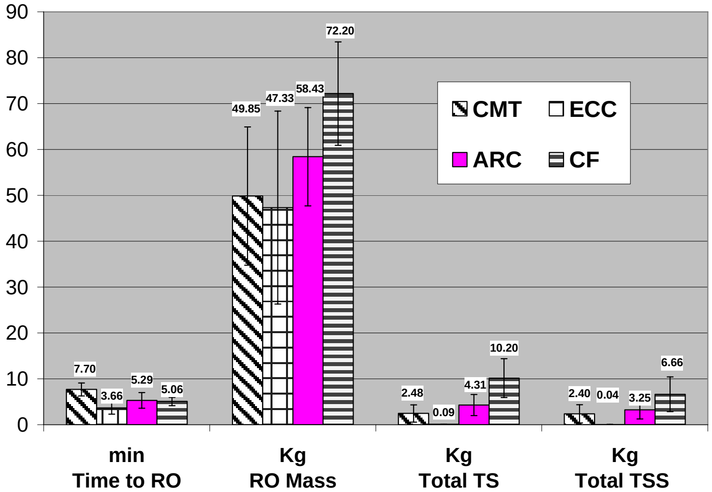

Figure 3. Time to initiate runoff, total mass of runoff and TS and TSS as affected by different treatments.

Runoff Quality

Table 2 presents physicochemical properties of runoff from the first flush (first liter of runoff collected directly from each plot) and from the subsequent runoff (total remaining runoff) samples. Treatment means and standard deviations of several parameters along with their statistical significance are shown in this table. All values represent total amounts (concentration x total runoff volume) of each parameter in the first flush and the subsequent runoff.

pH

Although the average pH for the rainwater was 5.6, the pH values for the runoff from all treatment plots were neutral or alkaline. This was due to the interaction of rainwater with alkaline soil (pH=8.13) and slightly alkaline compost, and compost/woodchips mix from different treatment plots during simulation runs. The pH for the first flush from the ECC plots was significantly lower than that for the first flush from the CF plots while all other treatments had statistically similar but lower pH values than the CF plots. In the remaining runoff, pH for all treatments increased as compared to the first flush and the remaining runoff from the ECC plots had significantly lower pH than that from all other treatment plots. The highest pH value measured from the remaining runoff was from CF plots. The increase of pH for all treatments in the remaining runoff was due to their higher TS and TSS content as compared to the first flush (Table 2). Also, the first flush and remaining runoff pH being the highest from the CF and the lowest from the ECC plots correspond to the highest TS and TSS in first flush and remaining runoff from the CF and the lowest TS and TSS in first flush and remaining runoff from the ECC plots.

TS and TSS

Total solids and TSS in the first flush from the ECC plots were significantly lower than those in the first flush from the CF plots while all other treatment had lower but statistically similar first flush TS and TSS than those in the first flush from CF plots. A similar trend for these parameters was observed in the remaining runoff from all treatment plots with the exception that the remaining runoff TS from the CF plots was significantly higher than that in remaining runoff from all other treatment plots. The TS and TSS in the first flush and the remaining runoff from all treatment plots followed a trend similar to the total mass of runoff (Figure 3). Table 3 also shows that most of the solids in first flush and remaining runoff from the CMT plots were measured as TSS and overall, plots amended with dairy manure compost or a compost/woodchip blend had lesser soil erosion than the CF treatment plots with no such amendments. This effect is also illustrated in Figure 4 that shows most (CF) to least (ECC) eroded surface conditions post rainfall.

Table 2. Total amounts of physicochemical constituents in runoff from different treatments.

	First Flush					Remaining Runoff			
PARAMETERS	CMT	ECC	ARC	CF		CMT	ECC	ARC	CF
pH	7.15^{ab*} (±0.92)**	7.0^{a} (±0.17)	7.53^{ab} (±0.23)	7.7^{b} (±0.36)		7.95^{a} (±0.21)	7.27^{b} (±0.15)	7.83^{a} (±0.12)	7.97^{a} (±0.12)
TS (Kg)	0.024^{ab} (±0.02)	0.003^{a} (±0.00)	0.032^{ab} (±0.02)	0.06^{b} (±0.04)		2.46^{a} (±1.88)	0.09^{a} (±0.04)	4.28^{a} (±2.29)	10.14^{b} (±4.25)
TSS (Kg)	0.019^{ab} (±0.02)	0.001^{a} (±0.00)	0.024^{ab} (±0.01)	0.04^{b} (±0.02)		2.38^{ab} (±1.98)	0.043^{a} (±0.02)	3.23^{ab} (±1.98)	6.62^{b} (±3.78)
TKN (mg)	13.95^{a} (±11.38)	17.73^{a} (±3.93)	18.6^{a} (±12.49)	54.73^{b} (±26.38)		$1,649^{a}$ (±1,517)	673^{a} (±276)	$1,806^{a}$ (±756)	$5,801^{b}$ (±1947)
NO_3-N (mg)	2.9^{a} (±0.89)	24.7^{a} (±32.2)	29.1^{a} (±5.08)	30.9^{a} (±22.27)		$1,556^{a}$ (±400)	873^{a} (±1,007)	871^{a} (±475)	$1,588^{a}$ (±974)
NH_4-N (mg)	0.4^{a} (±0.4)	2.9^{a} (±4.7)	0.7^{a} (±0.3)	9.4^{a} (±9.8)		205^{a} (±257)	6.7^{a} (±4.69)	16.1^{a} (±12.63)	430^{a} (±404)
P (mg)	3.85^{a} (±3.36)	5.91^{a} (±1.05)	6.4^{a} (±3.03)	17.9^{b} (±8.71)		515^{a} (±317)	258^{a} (±115)	582^{a} (±166)	$1,998^{b}$ (±883)
DP (mg)	0.36^{a} (±0.03)	3.84^{a} (±3.31)	1.83^{a} (±1.33)	6.5^{a} (±6.38)		57.07^{a} (±62.61)	66.26^{a} (±65.59)	69.52^{a} (±74.62)	516.65^{a} (±528.8)
K (mg)	267^{a} (±204)	498.5^{a} (±20.02)	348.2^{a} (±84.37)	476.2^{a} (±177.2)		$24,297^{ab}$ (±12,868)	$16,400^{a}$ (±7,052)	$24,545^{a}$ (±1,478)	$50,883^{b}$ (±16,914)
DK (mg)	4.1^{a} (±2.16)	75.6^{a} (±119.79)	120.5^{a} (±106.39)	68.9^{a} (±102.13)		560^{a} (±419)	$2,152^{a}$ (±3,275)	$2,437^{a}$ (±3,519)	465^{a} (±72)

* Averages in rows followed by different letters are different at 5% level. **Standard deviation

Figure 4. Post-rainfall plot surface conditions of each treatment.

Nitrogen, P and K

As mentioned earlier, all forms of N, P and K in Table 2 are total quantities determined from either the first flush (1-L) or remaining runoff from different treatment plots. As shown in Table 1, the highest rate of N, P and K was applied to the ECC plots followed by the CMT, ARC and CF plots. The TKN in the first flush and remaining runoff from the CF plots was significantly greater than that in the first flush and remaining runoff from all other treatments. The TKN in both forms of runoff from all other treatments was statistically similar. Despite much larger nitrogen applications to the ECC and CMT plots compared to the CAR and CF plots, the TKN, NO_3-N and NH_4-N in runoff from the ECC and CMT treatment plots were always lower than those in the runoff from the CF plots. This is attributed to the significantly higher solids and higher runoff mass from the CF treatment plots. Though highly variable within treatments and statistically similar among treatments, NO_3-N and NH_4-N in the first flush and the remaining runoff from the CF treatment plots were generally higher than those in the runoff from all other treatment plots. If NO_3-N in the first flush (1-L volume) and the remaining runoff from all treatment plots were converted to mg/l (total NO_3-N, mg divided by the remaining runoff mass, L), then with the exception of the first flush from the CMT plots, NO_3-N in runoff from all treatments will be above the 10 mg/l limits for the drinking water quality standards set by the US Environmental Protection Agency (EPA, 1994).

Total P in both forms of runoff from the CF treatment plots was significantly greater than that in runoff from all other treatment plots. The dissolved fraction of P (DP) was highly variable within treatments and statistically similar for either form of runoff from all treatment plots. Generally, DP in runoff was higher from the CF plots than all other treatment plots. As discussed above for the NO_3-N, if total P in either form of runoff were converted to mg/l, it will range from 3.86 ±3.36 mg/l in the first flush from the CMT plots to 27.02 ±8.4 mg/l in the remaining runoff from

the CF plots. These concentrations of total P, if introduced to receiving waters of lakes, streams and reservoirs will be much greater than the total P concentration of 100 µg/L, the upper limit of acceptable P to avoid eutrophication of such water bodies (Correll, 1998).
Total and dissolved K in the first flush and the remaining runoff were highly variable within each treatment and statistically similar for K in the first flush and DK in both forms of runoff from all treatments. Total K in the remaining runoff from CF plots was significantly higher than that in the runoff from the ECC and ARC treatments and higher but statistically similar from K in the runoff from the CMT plots.

CONCLUSION

Despite the shortest time to initiate runoff, the ECC plots had smaller total runoff mass than all other treatments and significantly lower TS and TSS in the runoff (first flush and the remaining) as compared to those in the runoff from CF plots. In the remaining runoff, TS from the CMT and ARC plots and TS and TSS from the CMT plots were also significantly lower than those from the CF plots. Overall, plots amended with DMC or DMC/woodchips blend produced less runoff and sediment in the runoff as compared to the mineral fertilizer plots without any organic amendment. All plots amended with organic materials received greater amounts of N, P and K as compared to the mineral fertilizer plots. Application rates for N, P and K for the ECC and CMT plots were generally one to two folds higher than those for the CF plots. Despite these very high application rates, TKN in runoff (first flush and the remaining) from the ECC, CMT and ARC plots was significantly lower than that in runoff from the CF plots. Also, statistically similar but lower NO_3-N and NH_4-N were measured in runoff from these treatment plots than those in the runoff from the CF plots. Total P in the CF plots' runoff was significantly higher and DP in runoff from the same plots was higher than but statistically similar to that in the runoff from all other treatments. Significantly higher K in the remaining runoff from the CF plots compared to that in the remaining runoff from the ECC and ARC plots was measured. Dissolved K in the first flush and the remaining runoff was statistically similar for all treatments but generally higher for ARC and ECC as compared to CMT and CF.

The ECC plots had smaller total runoff mass than all other treatments and significantly lower TS and TSS in the runoff as compared to those in the runoff from CF plots. Overall, plots amended with DMC or DMC/woodchips blend, though much higher in N, P and K, produced smaller runoff, and lesser sediment and nutrients in the runoff, as compared to the mineral fertilizer plots without any organic amendment. It was concluded that the ECC and CMT treatments established to control erosion and revegetate, respectively, a newly constructed road-right-of-way and shortly there after, subjected to rain (a worst case scenario) will be effective in erosion control. Although compared to the CF treatment, generally smaller quantities of N, P and K concentrations were measured in the runoff from the ECC and CMT treatment plots, N and P concentrations in the runoff were high from the standpoint of water quality.

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Use of Dairy Manure Compost as Erosion Control Material Under Vegetated and Non Vegetated Conditions

Mukhtar, S., M.L. McFarland, C.A. Wagner, B.L. Harris

INTRODUCTION

Many watersheds in the USA with large and concentrated animal feeding operations (CAFOs) face the challenge of reducing manure application rates on agricultural soils that test high in phosphorous (P) by identifying alternatives for manure utilization. Water quality studies in the Bosque River watershed, home to more than one hundred dairy operations, indicated that P was the limiting nutrient and that dairy waste application fields (WAFs) and municipal waste treatment plants were the major nonpoint and point sources of P, respectively, to the North Bosque River (McFarland and Hauck, 1999a, 1999b).

Studies by Persyn et al. (2004) and Risse and Faucette (2003) cite use of compost from various organic materials including animal manure for erosion control and revegetation of highway construction sites. Construction and erosion control applications of dairy manure compost (DMC) could provide an opportunity to remove large quantities of manure from the North Bosque River Watershed and help reduce the need for repeated application of manure to the same parcels of land in the watershed. However, very little information is available regarding runoff quantity and quality resulting from the use of manure-based compost materials, particularly on steep slopes and disturbed soils associated with roadway construction.

OBJECTIVES

The objectives of this study were to:

1. Examine the efficacy of using an erosion control treatment system containing composted dairy manure for stabilization and revegetation of steep slopes.
2. Compare results of runoff volume and concentrations and loadings of physicochemical constituents from experimental plots amended with a DMC/woodchips blend (designated as erosion control compost or ECC) or inorganic fertilizer (IF) subjected to simulated intense rainfall under non-vegetated and vegetated conditions.

METHODS AND MATERIALS

Experimental plot construction and set-up, treatment installation and vegetation establishment

Eight, 3 by 6-ft (0.9 by 1.8-m) plots were established on a custom built steel bed {9.1m (30ft) × 1.8m (6ft) × 228.6mm (9in) deep} divided with metal borders and lined with a 5 mil plastic tarp (Fig. 1a). At the downslope end of each plot, a triangular tray and downspout (Fig. 1b) were constructed to convey runoff to a sampling container.

Figure 1. Custom built steel bed lined with plastic tarp (a) and a triangular tray with downspout for coneying runoff to sampling containers (b).

Soil used to fill each divided metal bed (plot) was excavated from a constructed hillside at the Riverside campus in College Station, Texas, used by the Texas Transportation Institute (TTI) for runoff studies. Three composite soil samples were collected for laboratory analysis. Soil texture was clay loam containing an average 27, 35 and 38 percent sand, silt, and clay, respectively (Table 1). Additional soil chemical analyses conducted are listed in Table 2.

Table 1. Textural analysis of soil utilized to prepare sediment bed.

Plot ID	Sand	Silt	Clay	Texture
	------------------------%------------------------			
Soil Sample 1	26	34	40	Clay loam
Soil Sample 2	28	34	38	Clay loam
Soil Sample 3	28	36	36	Clay loam
Std Dev	*1.2*	*1.2*	*2.0*	
Average	27	35	38	

Table 2. Chemical analysis of soil utilized to prepare sediment bed.

Plot ID	pH	EC	NO_3+NO_2	P extractable	K	Ca	Mg	SO_4-S	Na	B	OM
Soil Sample 1	7.8	2246	43	7	239	9476	426	1213	215	0.44	1.53
Soil Sample 2	7.7	2118	60	8	229	8318	413	1356	242	0.41	1.59
Soil Sample 3	7.7	2094	50	8	230	8644	414	1902	181	0.47	1.60
Std Dev	*0.1*	*81.71*	*9.0*	*1*	*5.5*	*597*	*7.2*	*364*	*30.6*	*0.03*	*0.04*
AVERAGE	7.73	2153	51	8	233	8813	418	1490	213	0.44	1.57

In each plot, soil was added to a height of 7 inches (18 cm) and tamped down to a height of 4 inches (10 cm) with a 25 lb (11.4 kg) hand tamper (Fig 2a). The two treatment systems were erosion control compost (ECC); a 1:1 (v:v) blend of dairy manure compost (DMC) and woodchips, and inorganic fertilizer (IF). For the purpose of this paper, these treatment systems will be referred to as treatments. Both treatments were replicated four times and randomly assigned to these plots (Fig. 3). For each ECC plot preparation, the bed was filled up to 2 inches below the top of the bed by adding more soil to the previously tamped layer. A 150-lb (68 Kg) hand drum roller (22 inches wide) was used to break clods and level the soil surface (Fig. 2b). A similar procedure was used for IF plot preparation, but soil was filled to the top of the bed for this treatment. The procedure used to prepare the sediment beds was consistent with that utilized by TTI for bed preparation when conducting TxDOT approved research.

Figure 2. Soil compaction with hand tamping (a) and soil leveling with a drum roller (b).

For ECC plots, the blend of DMC and woodchips was applied on top of the soil as a 2-inch (5-cm) layer equivalent to 126 t/ac (91.1 t/ac DMC + 34.8 t/ac woodchips) or 283 mt/ha (Fig. 4). Based on chemical analysis of the DMC (Table 3a and 3b), this resulted in nutrient application rates of 1786 lb N/ac (2002 kg N/ha), 1272 lb P_2O_5/ac (1426 kg P_2O_5/ha), and 2678 lb K_2O/ac (3002 kg K_2O/ha). For the IF plots, granular fertilizer was hand broadcast and then lightly raked into the soil surface at rates of 100 lb N/ac (112 kg N/ha) as ammonium nitrate, 100 lb P_2O_5/ac (112 kg P_2O_5/ha) as triple superphosphate, and 100 lb K_2O/ac (112 kg K_2O/ha) as potassium chloride (Fig 4). These treatments were established 6 days prior to the first rainfall event. Total amounts of nutrients per plot and per acre for each treatment are presented in Table 3c. As noted in the table, due to the composition of the DMC, the ECC treatment resulted in substantially greater nutrient application rates compared to the IF treatment.

After establishment of treatments, all plots were seeded on the same day with a Texas DOT recommended seed mix (tall fescue, wheat, oats) with the addition of ryegrass to ensure vegetation establishment (Fig. 5a). The mixture was broadcast (Fig. 5b) and lightly raked into the surface of each plot. All plots were monitored for seed germination, moisture and insect management.

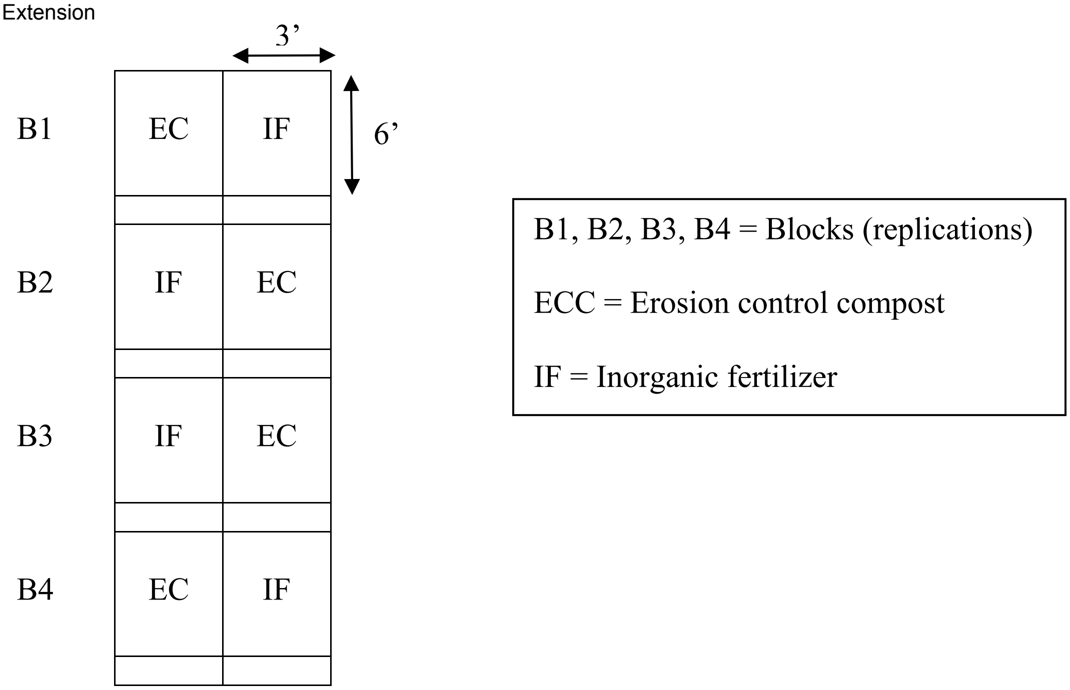

Figure 3. Experimental plots and treatment set-up (dimensions are not to scale)

Vegetation Response and Soil Sample Data Collection

Information on plant height and percent of canopy coverage is provided in Table 6. Average plant heights were measured from 10 individual plants randomly selected in each plot 47 days after planting (Fig. 6a). Percent canopy cover was measured by using a point method and ranking system; 1 for vegetation and 0 for no vegetation. Twenty-four individual points, 6 inches (15.2 cm) apart on the two 7-feet (2.1 m) diagonals crossing each plot were ranked (Fig. 6b). Measurements were made starting 6 inches away from plot borders to eliminate edge effects.

In addition to the initial composite soil samples collected and analyzed (Table 1 and 2), composite soil samples were collected from each plot at three stages of the study. Samples were collected (1) following the first rainfall simulation event; (2) after vegetation establishment, but prior to second rainfall simulation event; and (3) following the second rainfall simulation event. Each composite sample was collected by thoroughly mixing 10 subsamples collected at a 6 inch depth in each plot. Soil samples were submitted to TCE Soil, Water and Forage Testing Laboratory and analyzed according to the approved Marketing Composted Manure to Public Entities Quality Assurance Project Plan.

Table 3a. Laboratory analysis of dairy manure compost utilized in the rainfall simulation study. Parameters listed were determined on a wet weight basis.

Parameter	Units	Wet Weight Basis
Total N	%	0.98
Ammonia	mg/kg	584
Nitrate	mg/kg	8
Organic Nitrogen	%	0.92
Phosphorus as P2O5	%	0.69
Phosphorus	mg/kg	3048
Potassium as K2O	%	1.5
Potassium	mg/kg	12250
Calcium	%	9.1
Magnesium	%	0.52
Sulfate (SO4)	mg/kg	449
Copper	mg/kg	29
Zinc	mg/kg	90
Iron	mg/kg	5855
Manganese	mg/kg	153
Boron	mg/kg	19
Sodium	%	0.27
Chloride	%	0.17
pH	units	9.06
EC	mmhos/cm	4.165
Bulk Density	lb/cu ft	47
Carbonates as CaCO3	lb/ton	67
Organic matter	%	20.7
Organic Carbon	%	14.2
Ash	%	58.8
C:N Ratio	ratio	14
Moisture	%	20.5

Table 3b. Laboratory analysis of dairy manure compost utilized in the rainfall simulation study. Parameters listed were determined on a dry weight basis

Parameter	Units	Dry Weight Basis
Arsenic	mg/kg dw	3
Cadmium	mg/kg dw	less than 1
Chromium	mg/kg dw	6
Copper	mg/kg dw	36
Lead	mg/kg dw	2
Mercury	mg/kg dw	less than 1
Molybdenum	mg/kg dw	1
Nickel	mg/kg dw	5
Selenium	mg/kg dw	less than 1
Zinc	mg/kg dw	114
Cobalt	mg/kg dw	2
Total Solids	%	79.5
Fecal Coliform	mpn/g dw	17
Salmonella	mpn/4 g dw	less than 3
Respiration	mg CO2-C/g OM/day	7
Biological Avail. Carbon	mg CO2-C/g OM/day	7.2
Emergence	%	100
Relative Seedling Vigor	%	100
Description of plants	NA	Healthy
0.25" to 0.38"	% by weight	0
	% by volume	0
	Bulk Density (g/cc)	0
0.16" to 0.25"	% by weight	1.8
	% by volume	1.6
	Bulk Density (g/cc)	0.7
0.08" to 0.16"	% by weight	18.8
	% by volume	21.3
	Bulk Density (g/cc)	0.56
<0.08"	% by weight	79.4
	% by volume	77.1
	Bulk Density (g/cc)	0.65

Table 3c. Application rates of nitrogen (in the form of N), phosphorus (in the form of P_2O_5), and K (in the form of K_2O) per plot and per acre for each treatment, ECC and IF.

	N		P_2O_5		K_2O	
	lbs/plot	**lbs/A**	**lbs/plot**	**lbs/A**	**lbs/plot**	**lbs/A**
ECC	0.74	1786	0.53	1272	1.11	2678
IF	0.04	100	0.04	100	0.04	100
	lbs/plot		**lbs/plot**		**lbs/plot**	
Ratio of ECC:IF	18.5		13.25		27.75	

Figure 4. Metal bed plots with the IF treatment incorporated into soil and the ECC treatment applied on the soil surface.

Figure 5. Grass seed (left) being braodcast on IF treatment (right).

Figure 6. Plant height (a) and percent of canopy coverage (b) measurement .

Rainfall simulation and surface runoff sampling

In the fall of 2005, an indoor rainfall simulation facility owned and operated by TTI at Riverside campus was used to conduct rainfall simulations and runoff sampling experiments on non-vegetated and vegetated ECC and IF plots on September 26 and November 15, respectively. A detailed description of this facility is provided by Li et al. (2003).

An oscillating rain rack (Fig. 7), suspended 14 feet (4.3 m) above the test surface (ECC and IF plots) is equipped with drip emitters that produce 0.12 to 0.16 inch (3mm to 4mm) droplets to mimic a rainfall intensity of 3.5in/hr (88.9 mm/hr), which corresponds to a 25-yr return frequency of a 1-hr storm at the experimental site. Oscillation of the rack provides a randomized raindrop pattern for uniform coverage of treatment plots. The 25-yr 1-hr storm event is the typical rate used in highway roadside erosion control material testing in the TTI rainfall simulation facility (Li et al. 2003).

The steel bed with established treatements was hoisted under the rain rack (Fig. 7 and 8 for non-vegetated and vegetated conditions, respectively) at a 3:1 side slope to mimic road right-of-way.

Tap water was used for both rainfall simulation events. Chemical analysis of tap water samples collected at the time of each rainfall simulation event are presented in Table 8.

At the downstream end of each plot, a reinforced 2-inch diameter plastic hose was connected to the downspout of each plot to collect the first flush (first litre of runoff) and the subsequent total runoff for a period of 30 minutes following runoff initiation.

For both rainfall events, time to initiate runoff (time difference between start of simulated rainfall and beginning of overland flow) for each plot was recorded. Runoff was collected for a total of 30 minutes. The first liter of runoff (first flush) was collected directly in a plastic bottle (Fig. 9a) and subsequent runoff from each plot was collected into individual clean 30-gallon (113 L) plastic containers (Fig. 9b) and weighed for total runoff mass (Fig 10a). After weighing, contents of each container were thoroughly agitated to re-suspend solids, and a representative sub-sample was collected in a plastic bottle (Figs. 10a-c). This procedure of weighing and sampling was repeated for all plots during both rainfall events.

Because the sediment beds were to be placed outdoors between rainfall events, 3 small incisions (approximately 3 cm in length) were placed in the plastic lining under each plot. The cuts aided water flow through the plots so rainfall and irrigation applied to the bed would not pool in each plot. Prior to the second rainfall event, each incision was sealed with caulking to avoid leaks during rainfall simulation.

Figure 7. Oscillating rain rack with emitters (left) and non-vegetated treatment plots (right) hoisted under the rack at a 3:1 sideslope.

Figure 8. Rainfall simulation on vegetated ECC and IF treatment plots.

Analysis of soil, compost and runoff

Soil, compost and runoff water sample collection and laboratory analyses followed approved procedures and methodologies described in the Marketing Composted Manure to Public Entities Quality Assurance Project Plan. Table 4 lists analytes determined for soil and runoff water samples and the corresponding procedure for the analysis of each parameter. Three composite samples of dairy manure compost were collected prior to treatment installation and analyzed by Soil Control Laboratories. Parameters and laboratory methodology as defined by the Test Methods for the Examination of Compost and Composting are listed in Table 5.

Figure 9. Samples of first flush (a) and subsequent runoff (b) being collected during rainfall simulation event.

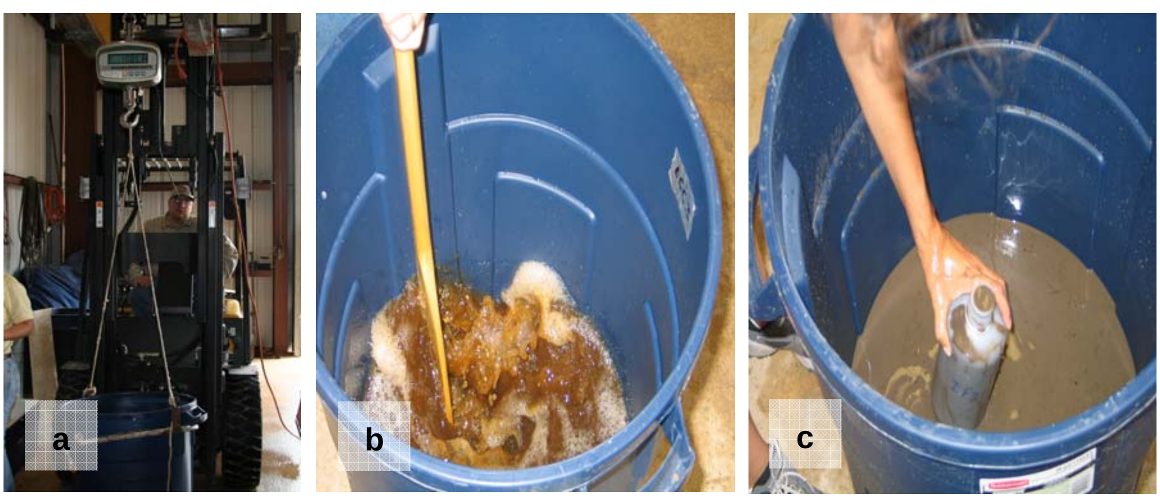

Figure 10. Weighing (a), mixing (b) and sub-sampling (c) of total runoff mass.

Table 4. Soil and runoff water sample parameters analyzed and the corresponding methodology as defined by the Soil, Water and Forage Testing Laboratory.

Parameter	SWFTL[a] Method
Soil	
pH	0015
Electrical Conductivity	0015
NO_3–N + NO_2–N (NNN)	0014
Extractable Phosphorus	00079 & 00081
Water Soluble P (CaCl)	0064
Potassium	00079 & 00081
Calcium	00079 & 00081
Magnesium	00079 & 00081
Sodium	00079 & 00081
Sulfate-Sulfur	00079 & 00081
Boron	0022 & 00081
Moisture	NA
Organic Matter	NA
Water	
pH	0041
Electrical Conductivity	0040
NO_3–N + NO_2–N (NNN)	0038
Total Phosphorus	0037
Ortho-phosphate	0061 & 0062
Potassium	0037
Calcium	0037
Magnesium	0037
Sodium	0037
Sulfate-Sulfur	0037
Total Solids	0057[b]
Total Suspended Solids	0057

[a] SWFTL = Soil, Water and Forage Testing Laboratory SOP code
[b] Standard Operating Procedure 0057 based on Standard Method 2540 (Franson 1989)

Table 5. Dairy manure compost sample parameters analyzed and corresponding methodology utilized by Soil Control Laboratories.

Parameter	**CL[a] Method (TMECC[b] Method)**
Chemical Properties	
Electrical Conductivity	04.10-A
PH	04.11-A
Organic Properties	
Organic Matter	05.07-A
Fecal Coliform	07.01-B
Metals	
Magnesium	04.12-B/04.14-A
Sodium	04.12-B/04.14-A
Manganese	04.12-B/04.14-A
Copper	04.12-B/04.14-A
Calcium	04.12-B/04.14-A
Zinc	04.12-B/04.14-A
Iron	04.12-B/04.14-A
Arsenic	04.12-B/04.14-A
Chromium	04.12-B/04.14-A
Cadmium	04.12-B/04.14-A
Lead	04.12-B/04.14-A
Mercury	04.12-B/04.14-A
Molybdenum	04.12-B/04.14-A
Nickel	04.12-B/04.14-A
Selenium	04.12-B/04.14-A
Nutrients	
Total Nitrogen	04.02-D
Total Phosphorus	04.12-B/04.14-A
Total Potassium	04.12-B/04.14-A
Physical Properties	
Particle Size	02.02-B
Maturity	05.05-A
Stability	05.08-B
Moisture	03.09-A

[a] CL = Control Laboratories
[b] TMECC = Test Methods for the Examination of Composting and Compost

Statistical analysis

Data were analyzed using the ANOVA procedure for a randomized complete block design in Stat View (SAS Inc.), and means were separated using Fisher's least significant difference (LSD) method.

RESULTS AND DISCUSSION

Vegetation response

Vegetation response data are presented in Table 6. Average plant height for the ECC plots (15.6 inches) was significantly greater than that for the IF (11.7 inches) plots. This may have been influenced by moisture conservation due to the mulching effect of the ECC and/or by the greater nutrient levels in that treatment. However, percent canopy cover was not affected by treatment, averaging 98% for both ECC and IF.

Table 6. Plant height and canopy coverage data.

Treatment	Rep 1	Rep 2	Rep 3	Rep 4	Statistics
	Plant heights (in)				
ECC	14.5* ±1.53**	15.0 ±1.59	16.3 ±1.42	16.4 ±1.31	15.6 ±1.63
IF	13.2 ±1.74	11.7 ±1.98	12.2 ±1.95	9.7 ±1.18	11.7 ±2.12
	Canopy coverage (%)				
ECC	98%*	96%	97%	99%	
IF	97%	98%	98%	98%	

* Average; ** SD

Soil Characteristics

Soil sample results from the three sampling events are presented in Tables 7a, 7b and 7c. Application of the ECC treatment significantly increased percent organic matter in ECC plots compared to soil sample results prior to treatment. The application of ECC and IF treatments had no effect on soil pH levels and minimal effect on EC levels. Compost used in this study had a pH of 9.06 (Table 3a), which is above the TxDOT compost specification (pH must be between 5.5 and 8.5). Data presented here warrants further investigation of the pH specification as vegetation response and soil sample results indicated no harmful effects from utilizing a high pH dairy compost based material.

The drain holes did preclude development of a mass balance of soil nutrients for the plots. However, soil sample data as listed in Tables 7a, 7b and 7c provide information about the effects of compost and inorganic fertilizer on soil characteristics.

Table 7a. Composite soil sample characteristics of individual plots following first rainfall simulation event. Samples were collected and submitted to laboratory on September 28, 2005.

Plot ID	pH	EC	NO_3+NO_2	P[a]	P[b]	K	Ca	Mg	SO_4-S	Na	B	OM
		umho/cm	ppm									%
ECC Rep 1	7.7	1801	39	430	10.51	994	7424	680	2542	510	2.26	7.60
ECC Rep 2	7.7	1904	38	412	4.96	758	7897	668	2812	403	1.87	6.34
ECC Rep 3	7.7	2131	61	188	3.93	646	7954	516	3812	366	1.62	4.27
ECC Rep 4	7.7	1765	32	367	6.60	709	8004	646	2794	406	1.63	5.62
Std Dev	*0.0*	*164.7*	*13*	*111*	*2.89*	*152*	*267*	*75.7*	*562*	*61.9*	*0.30*	*1.39*
AVERAGE	7.7	1900	43	349	6.50	777	7820	628	2990	421	1.85	5.96
IF Rep 1	7.5	1986	89	36	<1	230	8481	419	5019	224	0.93	1.82
IF Rep 2	7.5	1998	102	19	<1	289	8730	410	5237	240	0.82	1.84
IF Rep 3	7.4	1969	99	21	<1	262	9436	436	6543	208	0.86	1.81
IF Rep 4	7.1	1306	111	17	8.25	251	7518	377	3767	234	0.95	1.93
Std Dev	0.19	339.4	9.1	8.7	-	24.6	793	24.8	1137	14.0	0.06	0.19
AVERAGE	7.38	1815	100	23	-	258	8541	411	5141	227	0.89	7.38

Table 7b. Composite soil sample characteristics of individual plots prior to second rainfall simulation event. Samples were collected and submitted to laboratory on November 11, 2005.

Plot ID	pH	EC	NO_3+NO_2	P[a]	P[b]	K	Ca	Mg	SO_4-S	Na	B	OM
		umho/cm	ppm									%
ECC Rep 1	7.5	1892	3	505	9.28	1210	7220	702	2132	655	2.556	2.6
ECC Rep 2	7.8	1498	3	403	4.34	766	7652	644	2521	547	1.87	6.78
ECC Rep 3	7.5	1669	46	368	2.28	687	8169	652	2770	526	1.711	5.44
ECC Rep 4	7.6	802	7	398	1.87	866	7278	632	2192	505	1.676	6.37
Std Dev	*0.14*	*471*	*21*	*59.9*	*3.40*	*230*	*437*	*30.8*	*298*	*66.7*	*0.41*	*1.88*
AVERAGE	7.6	1465	15	418	4.44	882	7580	658	2404	558	1.95	5.30
IF Rep 1	7.5	1574	15	22	<1	202	7148	310	2812	290	na	1.83
IF Rep 2	7.7	1805	3	28	1.67	229	8208	367	4297	312	0.823	1.73
IF Rep 3	7.4	2066	41	24	<1	229	8668	348	4405	312	0.975	1.78
IF Rep 4	7.6	1717	51	25	<1	248	8730	402	4722	342	0.987	2.17
Std Dev	*0.13*	*206.9*	*22*	*2.4*	*-*	*19.0*	*732*	*38.2*	*851*	*21.4*	*0.09*	*0.20*
AVERAGE	7.55	1791	27	25	-	227	8189	357	4059	314	0.93	1.88

Table 7c. Composite soil sample characteristics of individual plots following second rainfall simulation event. Samples were collected and submitted to laboratory on November 22, 2005.

Plot ID	pH	EC	NO_3+NO_2	P[a]	P[b]	K	Ca	Mg	SO_4-S	Na	B	OM
		umho/cm	ppm									%
ECC Rep 1	7.8	1889	4	792	8.45	1327	8598	916	2752	816	2.01	10.09
ECC Rep 2	7.7	2210	4	252	1.14	625	8800	578	4357	534	1.28	4.52
ECC Rep 3	7.7	2340	6	318	1.92	576	8969	645	4057	593	1.37	4.92
ECC Rep 4	7.6	2390	7	288	1.5	651	9453	628	4713	518	1.16	4.36
Std Dev	*0.1*	*225.3*	*2*	*254*	*3.48*	*356*	*365*	*152*	*855*	*138*	*0.38*	*2.76*
AVERAGE	7.7	2207	5	413	3.25	795	8955	692	3970	615	1.46	5.97
IF Rep 1	7.5	2320	13	38	0.15	304	9551	408	5303	383	0.91	1.74
IF Rep 2	7.5	2530	14	19	0.1	280	9749	442	5647	393	0.68	1.81
IF Rep 3	7.5	2920	16	21	0.26	280	10334	411	7522	364	0.77	1.89
IF Rep 4	7.6	2740	17	34	0.26	306	10354	427	6336	417	0.78	1.7
Std Dev	*0.0*	*259.7*	*1.8*	*9.4*	*0.08*	*14.5*	*409*	*15.7*	*979*	*22.1*	*0.09*	*0.08*
AVERAGE	7.53	2628	15	28	0.19	293	9997	422	6202	389	0.79	1.79

[a] extractable; [b] water soluble

Runoff volume characteristics of non-vegetated and vegetated ECC and IF treatments

Time to initiate runoff, total amount of rainfall, total mass of runoff water and runoff rate from ECC and IF treatment plots resulting from simulated rainfall under non-vegetated and vegetated conditions are presented in Table 8.

Both systems (IF and ECC) received the same intensity of rainfall (3.5 in/hr). However, due to the inherent hydrophilic property of organic matter and prevention of soil surface sealing by the 5-cm thick erosion control blanket in the ECC system, considerably more time was required to initiate runoff from ECC plots compared to IF plots. Therefore, the ECC plots received rain for longer duration than the IF plots. Thus, ECC received a greater amount of rainfall under both vegetated and non-vegetated conditions.

Non-vegetated conditions: The average time to initiate runoff from non-vegetated ECC plots was nearly twice that of the IF plots, but was not significantly different due to large within treatment variation for ECC plots. The within treatment variation observed for ECC during the non-vegetated simulation was attributed in part to preferential flow or channeling along borders of selected plots, which was corrected for the vegetated simulation. Regardless, average total runoff mass from IF was significantly greater ($P \leq 0.05$) than that from ECC indicating more water infiltrated into the ECC plots than IF plots.

Runoff rates (cm/h) from ECC and IF plots were calculated from total runoff water mass (converted to volume using density of water), surface area (18 ft^2 or 1.67 m^2) and the time (30 min.) for runoff collection from each plot. During the non-vegetated rainfall event, average runoff rate for ECC was significantly lower than IF. Surface sealing due to raindrop impact on the bare soil surface of IF treatment plots reduced infiltration and rain water and initiated quicker overland flow as compared to ECC where the woodchips and compost protected the soil surface. Figure 11 illustrates post rainfall evidence of sealing and rill formation due to detachment and transport of sediment on IF plot surfaces as compared to no visible structural damage to the soil protected by ECC treatment. In addition, the significantly higher organic matter content (5.96%±1.68 for ECC vs. 1.85% ±0.05 for IF, n=4) and the hydrophilic nature of compost in the ECC treatment resulted in a significantly lower runoff rate and less total runoff water mass from ECC plots as compared to the IF plots.

Vegetated conditions: Similar to results observed for non-vegetated conditions, simulated rainfall on vegetated plots resulted in greater average time to initiate runoff from ECC compared to IF plots, but differences were statistically significant in this case (Table 8). The substantial delay in initiation of runoff from ECC plots indicated that such treatments may completely prevent runoff when exposed to rainfall of this intensity for short periods of time (less than 20 minutes) as compared to exposed soil (IF treatment).

Considerably more time (>20 minutes longer) was required to initiate runoff from vegetated ECC plots compared to vegetated IF plots. Thus, ECC plots received a much greater amount of rainfall, which resulted in increased runoff rate and mass. As a result, the total mass of runoff water and runoff rate from vegetated ECC plots were significantly greater than from vegetated IF plots despite the fact that ECC plots absorbed and retained more of the rainfall applied than the

IF plots. As noted in Table 8, the ECC plots absorbed more water than the IF plots during the entire vegetated rainfall simulation event.

Comparison of non-vegetated and vegetated conditions: Vegetated IF plots initiated runoff sooner (about half the time observed for non-vegetated IF plots) but had less than half the runoff rate and total mass of runoff water as compared to the non-vegetated IF plots. Surface sealing caused by raindrop impact on the exposed soil of the non-vegetated IF plots likely explain this result. Established vegetation on the IF plots slowed runoff rate and improved water infiltration.

Vegetated ECC plots took much longer to initiate runoff and had twice the runoff rate and total runoff mass compared to the non-vegetated ECC plots. The ECC treatment coupled with vegetation improved infiltration and substantially delayed runoff for vegetated ECC plots compared to non-vegetated ECC plots (~15 minutes to runoff under non-vegetated conditions versus ~26 minutes to runoff for vegetated conditions). This delay in runoff led to increased rainfall exposure time for vegetated ECC plots (~45 minutes rainfall exposure for non vegetated conditions versus ~56 minutes rainfall exposure for vegetated conditions). Although no data were collected to determine the saturation point of the plots, the behavior of the ECC plots during the second rainfall simulation event implies the plots reached a saturation point prior to producing runoff, thereby suggesting that once runoff was initiated, the amount of runoff collected was directly proportional to the amount of rainfall applied contributing to greater runoff volume and mass.

In comparing IF and ECC treatments, ECC retained greater amounts of rainfall than IF under both vegetated and non-vegetated conditions. This indicates that the ECC treatment in contrast to the IF treatment would prevent runoff from equal intensity, relatively short duration rainfall events, especially under vegetated conditions. This is further corroborated by greater water retention within ECC plots and thus, significantly greater delay in initiation of runoff under vegetated conditions from ECC plots compared to IF plots.

A final observation following non-vegetated and vegetated rainfall simulation events occurred when the incisions were made in the plastic lining to allow for drainage after and between rainfall or irrigation events. When the incisions were made, water immediately drained from the plots indicating thorough infiltration. In deeper profiles, it is possible that more water would have saturated the soils and produced less runoff. The plots in the constructed sediment bed, however, mimic those possible on road right-of-ways with profile limiting conditions, such as shallow soils (e.g. depth to bedrock) or compacted subsoils.

Table 8. Time to initiate runoff, total runoff mass, and runoff rate from non-vegetated and vegetated ECC and IF treatment plots.

	Non-Vegetated		Vegetated	
Parameters	**ECC**	**IF**	**ECC**	**IF**
Time to Runoff[3] (min.)	15.11[1] (±11.03)[2]	8.84 (±1.28)	26.49[a] (±1.34)	4.82[b] (±1.57)
Total Rain Water (kg or L[4]) ***applied to plot***	112.36 (±27.40)	96.81 (±3.19)	140.36[a] (±3.10)	86.81[b] (±3.65)
Total Runoff Water (kg) ***received from plot***	24.84[a] (±7.68)	48.62[b] (±5.30)	48.38[a] (±5.69)	20.98[b] (±3.26)
Runoff Rate (cm/hr)	2.97[a] (±0.92)	5.81[b] (±0.64)	5.79[a] (±0.68)	2.51[b] (±0.39)

[1] Non-vegetated or vegetated ECC and IF treatment means within a row followed by different letters are significantly different at the 5% level.
[2] Standard deviation.
[3] Time to runoff was calculated by determining the amount of time lapsed between the rainfall simulation system being fully charged and the point at which runoff from the plot began. Rainfall simulation system was fully charged within 1 min 45 sec and 1 min 15 sec of first drop during the first and second rainfall simulation events, respectively.
[4] Liters of water converted to kg water assuming density of water is 1 kg/L

Figure 11. Post rainfall IF and ECC treatment plot surface conditions from non-vegetated simulation event.

Runoff Quality of non-vegetated and vegetated ECC and IF treatments

The physicochemical parameters analyzed in the tap water used for the rainfall simulation, and for first flush and remaining runoff samples during non-vegetated and vegetated rainfall simulation events on ECC and IF plots are presented in Table 9. All analytes for ECC and IF except solids, pH and ECC in Table 9 are concentrations (mg/L) determined from either the first flush (1-L) or remaining runoff from non-vegetated or vegetated rainfall simulation events. All solids are total quantities determined from either the first flush or the total mass of remaining runoff from ECC and IF treatments. Analysis of the tap water revealed alkaline (pH: 8.1) water with trace amounts of TKN, nitrite + nitrate (NNN), P, K, Ca, and S. Tap water TS was mostly dissolved solids and Na was a major constituent of the tap water TDS.

pH, Sodium and Electrical Conductivity

Under non-vegetated conditions, the pH of first flush and remaining runoff samples from ECC plots was significantly greater than that in corresponding samples from IF plots (Table 9). Greater sodium and elevated total salt concentrations resulting from the compost component of the ECC treatment likely were contributing factors. In contrast, pH values for both first flush and remaining runoff samples from vegetated plots were greater for IF than ECC. However, sodium and total salt levels were greater in ECC plots. The transition in pH, therefore, was likely due to two modifying factors related to the compost. First, organic matter decomposition, which likely occurred in ECC plots, results in the release of organic acids which can have a direct impact on runoff pH. Organic acids can chelate certain inorganic minerals, thereby reducing effective salt loads and altering the pH effects typically associated with soluble salts. Secondly, substantially greater nitrogen concentrations in the ECC plots, as evidenced by elevated runoff TKN concentrations, likely resulted in lower pH levels due to nitrification of ammonium.

Total Solids, Total Dissolved Solids and Total Suspended Solids

As noted above, due to the physical characteristics of the manure and woodchips mixture in the ECC system, considerably more time was required to initiate runoff from ECC plots compared to IF plots. Therefore, the ECC plots received rain for longer duration than the IF plots. Thus, ECC received a greater amount of rainfall under both vegetated and non-vegetated conditions.

Non-vegetated conditions: Under non-vegetated conditions, TS and TSS were significantly lower in the first flush and remaining runoff from the ECC plots compared to IF plots (Table 9). Total dissolved solids in ECC runoff tended to be slightly higher but were statistically similar to IF runoff. Differences between concentration of solids within ECC treatments could have resulted from the preferential flow or channeling along the plot border, which resulted in quicker runoff from 2 of the 4 replications. Most TS from ECC runoff was in the form of dissolved solids while most TS from IF runoff was in the form of TSS. This suggests that a majority of solids in the runoff from the ECC plots were constituents in dairy manure compost that dissolved in the rainwater, while most solids in the IF runoff were eroded soil sediment detached due to the direct impact of the simulated rainfall and transported out of the IF plots by the overland flow. Overall, lower sediment yield in the first flush and remaining runoff from ECC followed a trend similar to the runoff rate and total mass of runoff water (Table 7) from these non-vegetated plots. All ECC plots had less soil disturbance from raindrop impact than IF plots. This effect is visually illustrated by plot photographs in Figure 11 which show the more eroded surface conditions for IF compared to ECC plots post simulated rainfall under non-vegetated conditions.

Vegetated conditions: Following establishment of vegetation, simulated rainfall produced significantly higher TDS in the first flush from ECC plots than IF plots, while TS and TSS in the first flush from ECC plots were statistically similar to those from IF plots (Table 9). The remaining runoff from vegetated ECC plots had significantly higher TS and TDS than those in the runoff from vegetated IF plots. This trend was due to significantly higher runoff rate and total runoff volume from vegetated ECC plots than those from the vegetated IF plots. However, TSS in the remaining runoff from vegetated IF plots again were significantly higher than those from vegetated ECC plots. As in the non-vegetated rainfall event, solids in the runoff from vegetated ECC plots were primarily in the form of dissolved solids, while solids in the runoff from vegetated IF plots were dominantly in the form of suspended solids.

Comparison of non-vegetated and vegetated conditions: Lower overall total solids (sediment) in the runoff from IF plots under vegetated conditions as compared to non-vegetated conditions were due to the vegetative cover that reduced overland flow (runoff rate and total mass of runoff water, Table 8) and reduced soil erosion from these plots as compared to the non-vegetated IF plots (Table 9). In contrast, vegetated ECC plots had greater overall total solids in the runoff under vegetated conditions compared to non-vegetated conditions but most of the vegetated ECC plot runoff solids were in the form of dissolved solids. Greater total mass of runoff as a result of higher runoff rate from vegetated ECC (Table 8) plots versus non-vegetated ECC plots resulted in higher TS from the vegetated ECC. Greater time to initiate runoff for vegetated ECC plots as compared to the non-vegetated ECC plots (Table 8) also provided more interaction time between compost and rainwater enhancing the dissolution of soluble compost constituents and their transport in overland flow.

Nitrogen, Phosphorous and Potassium

Due to the nutrient composition of the dairy manure compost used in the study, very high rates of N, P, and K were applied to the ECC plots as compared to IF plots. In addition, due to the inherent property of the ECC system, considerably more time was required to initiate runoff from ECC plots compared to IF plots. Thus, ECC received more rainfall under both vegetated and non-vegetated conditions.

The TKN in the first flush and remaining runoff from non-vegetated and vegetated ECC plots was significantly greater than that in corresponding IF plots. The TKN in first flush and remaining runoff from the vegetated ECC and IF plots decreased as compared to corresponding first flush and remaining runoff from non-vegetated ECC and IF plots. The percentage decrease was greater for the ECC treatment compared to the IF treatment.

The NNN in the first flush and remaining runoff from non-vegetated ECC plots was statistically similar to that in corresponding non-vegetated IF plots (Table 9). In contrast, NNN in the first flush and remaining runoff from vegetated ECC plots was significantly lower than that from vegetated IF plots.

Soluble P (ortho P) concentrations in the first flush from non-vegetated ECC plots tended to be greater, but were statistically similar to those in corresponding non-vegetated IF plots. However, ortho P concentrations in the remaining runoff from non-vegetated ECC plots were significantly greater than those in corresponding IF plots. Similarly, for the vegetated plots, ortho P concentrations in the first flush and remaining runoff of ECC plots were significantly greater than those in corresponding IF plots. Concentrations of ortho P from vegetated plots remained fairly consistent in both first flush and remaining runoff for ECC and IF treatments.

Total P concentrations in the first flush remaining runoff from non-vegetated ECC plots were significantly greater than those in the remaining runoff from the non-vegetated IF plots. A similar trend was observed for total P in first flush samples, although differences were not significant. For vegetated conditions, total P concentrations in the first flush and remaining runoff from ECC plots were significantly greater than those from corresponding IF plots. Total P concentrations in the first flush and remaining runoff from both ECC and IF plots were considerably lower once vegetation was established.

Potassium (K) concentrations in the first flush and remaining runoff from the non-vegetated and vegetated ECC plots were significantly greater than those in corresponding IF plots. Concentrations of K in the first flush and remaining runoff from the vegetated ECC plots were about one half of those in the first flush and remaining runoff from the non-vegetated ECC plots. Conversely, K concentrations remained effectively unchanged in the first flush and remaining runoff from the vegetated IF plots.

Total masses of primary nutrients (N, P and K) were determined by summing weights calculated using runoff volume and nutrient concentrations for first flush and remaining runoff for each treatment under non-vegetated and vegetated conditions (Table 10). The ECC plots substantially delayed runoff and therefore received more rainfall than the IF plots. In addition, due to higher nutrient levels in the compost, the ECC plots received substantially greater nutrient applications (Table 3c) than the IF plots. Both factors contributed to the greater total nutrient mass losses of nitrogen, phosphorus and potassium. Total masses of TKN were significantly greater for ECC under both non-vegetated (4 fold) and vegetated (7 fold) conditions compared to IF. Total masses of nitrate and nitrite (NNN) were not different for ECC compared to IF under non-vegetated or vegetated conditions. Total masses of ortho P and total P were not different for ECC compared to IF for non-vegetated conditions; however, ECC produced significantly greater masses (more than 10 fold) of both ortho P and total P compared to IF under vegetated conditions. Total masses of K were significantly greater (more than 10 fold) for ECC than IF under both vegetated and non-vegetated conditions. For comparison, Table 11 provides the concentration of primary nutrients (N, P and K) on a mass per acre or hectare basis.

Due to differences in rainfall exposure time on ECC and IF plots under vegetated conditions, ratios of total mass of TKN, total P and K losses in the runoff from these treatments were compared to ratios of rainfall exposure time, runoff mass and total water retained (difference between average total rainfall applied to a plot and average total runoff collected from a plot).

Results of these calculations are presented in table 12. In addition, the ratio of total N, P_2O_5 and K_2O applied in the ECC and IF systems were compared and presented in table 3c.

While the ratio of rainfall exposure time was similar for non-vegetated conditions, runoff mass was only half for ECC compared to IF. Nevertheless, TKN and total K losses from ECC plots were nearly 4.7 and 17.9 times greater than IF plots, respectively. Total P losses were similar from both treatment systems.

Under vegetated conditions, ECC had a total rainfall exposure time 1.6 times and total runoff mass 2.3 times greater than IF. But, ECC nutrient losses were 8, 13, and 33 times greater than IF for TKN, total P, and total K, respectively.

Under both non-vegetated and vegetated conditions, ECC plots received 1.16 and 1.62 times more rainfall than IF plots, yet retained 1.82 and 1.40 times more water than IF plots, respectively. ECC yielded greater nutrient losses under both conditions.

A comparison of nutrient ratios for ECC and IF treatments indicates that despite more rainfall exposure time, lower total runoff mass and greater water retention under non vegetated conditions and greater rainfall exposure time, total runoff mass and water retention under vegetated conditions, the ECC plots yielded much greater nutrient losses as compared to IF plots. These greater nutrient losses from ECC plots were most likely due to the fact that when compared to the IF treatment, the ECC treatment resulted in 18.5, 13.25 and 27.75 times greater rates of application of N, P_2O_5 and K_2O, respectively (Table 3c). Chastain et. al. (2006) determined that a 5 cm application of an erosion control blanket (a mixture of composted cow manure with wood waste) resulted in application rates of P_2O_5 and K_2O that were in excess of agronomic rates for the crop.

Sulfur, Calcium, Magnesium

Sulfur and sulfate concentrations in the first flush of non-vegetated IF plots were greater than those in ECC plots; however, concentrations were not different in remaining runoff. Under vegetated conditions, both sulfur and sulfate concentrations were significantly greater in the first flush and remaining runoff of ECC plots compared to corresponding IF plots. Calcium concentrations in the first flush collected from the ECC plots during the non-vegetated rainfall event were significantly lower than the first flush collected from the IF plots. All other calcium concentrations under non-vegetated conditions tended to be consistent in runoff; however, Ca concentrations in both first flush and remaining runoff of vegetated plots were significantly greater from ECC treatments. This may have been due to Ca additions from the compost application and/or Na substitution for Ca in ECC plots, which had greater Na levels. A similar response was observed for Mg under vegetated conditions.

Table 9. Total mass or concentration of physicochemical constituents in first flush, remaining runoff and tap water.

	Non-Vegetated				Vegetated				Tap Water
Sample ID	**First Flush**		**Remaining Runoff**		**First Flush**		**Remaining Runoff**		**1-L n=2[#]**
Parameters	**ECC**	**IF**	**ECC**	**IF**	**ECC**	**IF**	**ECC**	**IF**	
pH	8.6*[a] (±.0001)**	7.9 [b] (±.096)	8.4[a] (±.29)	7.9 [b] (±.0001)	8.2[a] (±.082)	8.6 [b] (±.082)	8.0 [a] (±.0001)	8.4 [b] (±.082)	8.1
EC μmohs/cm	1742 (±387)	1343 (±48)	2183 (±623)	1248 (±65)	2365 [a] (±525)	907 [b] (±38)	2885 [a] (±176)	903 [b] (±76)	843
TS (Kg)	0.003[a] (±.0001)**	0.019[b] (±.01)	0.084[a] (±0.03)	0.671[b] (±0.147)	0.0024 (±0.0004)	0.0027 (±0.003)	0.132[a] (±0.003)	0.034[b] (±0.004)	0.0005 (±0.0001)
TDS (Kg)	0.002 (±0.0006)	0.001 (±0.0001)	0.061 (±0.036)	0.048 (±0.0005)	0.0022[a] (±0.0005)	0.0005[b] (±0.0002)	0.128[a] (±0.005)	0.013[b] (±0.003)	0.0005 (±0.0001)
TSS (Kg)	0.0017[a] (±0.0003)	.0182[b] (±0.006)	0.026[a] (±0.005)	0.6[b] (±0.002)	0.0004 (±0.0002)	0.0025 (±0.002)	0.011[a] (±0.003)	0.027[b] (±0.006)	--
TKN (mg/L)	48.7[a] (±19.92)	6.65[b] (±0.73)	52.1[a] (±10.64)	5.90[b] (±0.00)	15.18[a] (±2.29)	4.83[b] (±1.09)	17.53[a] (±2.91)	4.98[b] (±0.88)	2.7 (±0.42)
NNN (mg/L)	0.63 (±0.68)	1.52 (±0.24)	1.36 (±0.99)	0.42 (±0.06)	0.81[a] (±0.54)	2.97[b] (±1.11)	0.95[a] (±0.42)	1.54[b] (±0.48)	0.2 (±0.16)
Ortho P (mg/L)	1.59 (±0.27)	0.84 (±0.36)	1.57[a] (±0.49)	0.94[b] (±0.19)	1.92[a] (±0.68)	0.38[b] (±0.19)	2.36[a] (±0.40)	0.40[b] (±0.14)	0.047 (±0.024)
Total P (mg/L)	13.25 (±3.39)	5.49 (±3.12)	11.61[a] (±2.72)	5.36[b] (±1.34)	1.89[a] (±0.38)	0.46[b] (±0.17)	2.29[a] (±0.30)	0.40[b] (±0.08)	0.21 (±0.02)
S (mg/L)	31.26[a] (±14.11)	132.3[b] (±52.56)	121.2 (±110.07)	100 (±16.63)	256.4[a] (±75.02)	15.73[b] (±4.57)	384.8[a] (±23.06)	16.20[b] (±14.84)	3.47 (±0.48)
SO4-S (mg/L)	93.6[a] (±42.24)	396.2[b] (±157.39)	362.9 (±329.60)	299.1 (±49.81)	767.6[a] (±224.65)	47.1[b] (±13.69)	1152[a] (±69.04)	48.5[b] (±44.44)	10.4 (±1.43)
K (mg/L)	219.3[a] (±95.65)	8.11[b] (±2.16)	229[a] (±26.64)	6.70[b] (±0.89)	104.42[a] (±43.27)	10.29[b] (±1.32)	117.3[a] (±33.55)	7.98[b] (±1.41)	3.2 (±0.87)
Ca (mg/L)	11.68 (±2.76)	172 (±54.74)	124 (±135.88)	125.6 (±20.02)	277.6[a] (±78.94)	34.04[b] (±8.37)	411[a] (±64.98)	30.05[b] (±12.84)	3.15 (±0.28)
Mg (mg/L)	3.80[a] (±1.052)	10.40[b] (±2.51)	14.12 (±12.45)	7.33 (±0.96)	27.72[a] (±9.25)	2.05[b] (±0.51)	39.1[a] (±4.96)	1.81[b] (±0.75)	0.53 (±0.007)
Na (mg/L)	285.2[a] (±28.91)	223.2[b] (±3.58)	283.23[a] (±18.60)	224[b] (±2.25)	303[a] (±56.84)	201.5[b] (±4.18)	299[a] (±37.75)	200[b] (±2.82)	219 (±22)

* Means within non-vegetated and vegetated categories and sampling periods (first flush or remaining runoff) followed by different letters are significantly different at the 5% level.
** Standard deviation
\# For tap water, n= 1 for pH and EC

Table 10. Total mass of nitrogen, phosphorus and potassium parameters in first flush and remaining runoff under non-vegetated and vegetated conditions.

	Non-Vegetated		Vegetated	
Parameters	**ECC**	**IF**	**ECC**	**IF**
TOTAL WATER [Kg]	24.84[a*] (±7.68)**	48.62[b] (±5.31)	48.38[a] (±5.69)	20.98[b] (±3.27)
TKN [mg]	1349[a] (±647)	287.6[b] (±31.05)	834[a] (±55.85)	104.8[b] (±28.60)
NNN [mg]	38.72 (±33.64)	21.43 (±4.91)	44.30 (±14.94)	32.7 (±5.38)
Ortho P [mg]	36.76 (±6.02)	45.90 (±11.43)	112.3[a] (±11.16)	8.20[b] (±2.35)
Total P [mg]	275.6 (±38.66)	262.2 (±74.32)	109.4[a] (±9.97)	8.26[b] (±1.10)
K [mg]	5829a (±2303)	325.9b (±43.51)	5582a (±1405)	167.4b (±21.18)

* Non-vegetated or vegetated ECC and IF treatment means within a row followed by different letters are significantly different at the 5% level.
** Standard deviation.

Table 11. Rate of nutrient loss (lbs/ac or kg/ha) contained in runoff from non-vegetated and vegetated ECC and IF plots. (Calculations based on total mass presented in Table 7).

	Non-Vegetated		Vegetated	
Parameters	**ECC**	**IF**	**ECC**	**IF**
	lb/A			
TKN	7.20[a] (±3.45)	1.53[b] (±0.17)	4.45[a] (±0.30)	0.56[b] (±0.15)
NNN	0.21 (±0.18)	0.11 (±0.03)	0.24 (±0.08)	0.17 (±0.03)
Ortho P	0.20 (±0.03)	0.24 (±0.06)	0.60[a] (±0.06)	0.04[b] (±0.01)
Total P	1.47 (±0.21)	1.40 (±0.40)	0.58[a] (±0.05)	0.04[b] (±0.01)
K	31.10[a] (±12.29)	1.74[b] (±0.23)	29.79[a] (±7.50)	0.89[b] (±0.11)
	kg/ha			
TKN	8.07[a] (±3.86)	1.72[b] (±0.19)	4.99[a] (±0.33)	0.63[b] (±0.17)
NNN	0.23 (±0.20)	0.13 (±0.03)	0.26 (±0.09)	0.20 (±0.03)
Ortho P	0.22 (±0.04)	0.27 (±0.07)	0.67[a] (±0.07)	0.05[b] (±0.01)
Total P	1.65 (±0.23)	1.57 (±0.44)	0.65[a] (±0.06)	0.05[b] (±0.01)
K	34.84[a] (±13.76)	1.95[b] (±0.26)	33.37[a] (±8.40)	1.00[b] (±0.13)

* Non-vegetated or vegetated ECC and IF treatment means within a row followed by different letters are significantly different at the 5% level.
** Standard deviation.

Table 12. Comparison of ratios of rainfall exposure time, runoff mass and nutrient losses for ECC and IF treatments under non-vegetated and vegetated conditions.

Parameter	Ratio of ECC:IF							
	--------------non–vegetated---------------				-----------------vegetated------------------			
		TKN	Total P	K		TKN	Total P	K
Ratio of rainfall exposure time*	**1.16**	4.69	1.05	17.89	**1.62**	7.96	13.24	33.35
Ratio of runoff mass	**0.51**	4.69	1.05	17.89	**2.31**	7.96	13.24	33.35
Ratio of total Water Retained**	**1.82**	4.69	1.05	17.89	**1.40**	7.96	13.24	33.35

A measurement of total rain water applied
** The difference between total rainfall volume and the runoff volume

SUMMARY

Simulated rainfall was applied to constructed plots set on a 3:1 slope that received an application of either erosion control compost (dairy manure compost/woodchips; 1:1 volume mixture) or inorganic fertilizer under non-vegetated and vegetated conditions. Time to initiate runoff was greater for ECC than IF under non-vegetated and vegetated conditions. Runoff rate and total runoff were greater for IF under non-vegetated conditions, but the reverse was true under vegetated conditions. Because considerably more time (>20 minutes longer) was required to initiate runoff from vegetated ECC plots compared to vegetated IF plots, the ECC plots received greater amounts of rainfall which resulted in increased runoff rate and mass.

Water pH values fluctuated somewhat for ECC and IF treatments for the non-vegetated and vegetated rainfall simulations, with values being higher for ECC under non-vegetated conditions and higher for IF under vegetated conditions. Higher initial Na and total salt levels in runoff from ECC plots during unvegetated rainfall simulation likely were offset by release of organic acids and nitrification, reducing pH values at the vegetated rainfall simulation. Total salt levels remained high in runoff from the vegetated ECC plots and were significantly greater than those in IF plots, which were similar to tap water.

Total suspended solids and TS in first flush and remaining runoff were significantly greater for IF plots than ECC plots under non-vegetated conditions due to substantially greater soil loss. In contrast, TS in remaining runoff of vegetated ECC plots were significantly greater than those in IF plots, but the bulk of the TS was in the form of TDS. Higher nutrient and salt levels in the compost likely contributed to this result.

Concentrations of TKN in the first flush and remaining runoff from both non-vegetated and vegetated ECC plots were significantly greater than those in corresponding IF plots. In addition, ortho P and total P concentrations in the remaining runoff from non-vegetated plots and both the first flush and remaining runoff of vegetated plots were significantly greater for ECC plots compared to IF. Likewise, K concentrations in the first flush and remaining runoff from non-vegetated plots were significantly greater for ECC than IF treatments, with similar results for vegetated plots although concentrations in ECC plots decreased by about 50%. Increased nutrient concentrations in runoff from the ECC plots compared to IF were most likely due to substantially greater total nutrient loadings as a result of the chemical composition of the manure-based compost utilized in the ECC treatment (ECC treatment application contained 18.5, 13.25 and 27.75 times greater rates of N, P_2O_5 and K_2O, respectively).

Total masses of TKN and K were significantly greater for ECC compared to IF under both non-vegetated and vegetated conditions. Total masses of both ortho P and total P were not different for ECC compared to IF under non-vegetated conditions, but were significantly greater for ECC than IF under vegetated conditions. Here again, the substantially greater total nutrient loadings resulting from use of manure compost in the ECC treatment likely explain these results. Numerous studies have reported a direct correlation between phosphorus losses, both in the dissolved and suspended solids fractions, as soil test phosphorus levels increase (Schwartz and Dao, 2005; Vietor, et al. 2003; Vietor, et al. 2002). Vietor et al, (2004) found no significant differences in P losses in the first runoff solution from plots which received similar P rates of inorganic fertilizer and composted dairy manure. However, P levels were significantly greater in runoff from the composted dairy manure plots compared to inorganic fertilizer plots for subsequent runoff events.

Due to the significant differences in rainfall exposure time on ECC and IF plots under vegetated conditions, ratios of total mass of TKN, total P and K losses in the runoff from these treatments were compared to ratios of rainfall exposure time, runoff mass and total water retained (difference between average total rainfall applied to a plot and average total runoff collected from a plot). This comparison of nutrient ratios for ECC and IF treatments indicates that due to greater rainfall exposure time, total runoff mass and water retention under vegetated conditions, and due to a greater application rate of N, P_2O_5 and K_2O, the ECC plots yielded greater nutrient losses as compared to IF plots.

This study supports previous work that has shown the benefits of organic soil amendments for reducing soil erosion, particularly from highly erodible surfaces. In the absence of vegetation, the ECC treatment significantly reduced the loss of solids during a runoff event. In addition, when vegetated, the use of an ECC material delayed runoff for a substantially longer time period than IF. Under both non-vegetated and vegetated conditions, the ECC treatment retained greater amounts of rainfall than the IF treatment.

However, when runoff events of equal duration, but disparate rainfall exposure time, under vegetated conditions were compared, the ECC plots produced more runoff than the IF plots. In addition, losses of N, P and K were greater for the compost amended plots (ECC) compared to IF. The continued mineralization of nutrients from compost over time may result in considerably greater nutrient loadings in runoff over the life of the treatment. Thus, reduced rates of compost and/or the use of compost materials with lower nutrient levels may be warranted where significant runoff is anticipated.

Data and nutrient balance calculations performed by Chastain et. al. (2006) clearly demonstrate that amendment application recommendations based on a prescribed volume (blanket depth) are not useful. Rather, application rates of nutrient rich materials, such as compost, should be determined based on the analysis of: (1) plant nutrients in the product, (2) nutrient requirements of the intended vegetation, and (3) soil-test results. Findings of this study support the recommendation made by Chastain et. al. (2006). A total nutrient analysis of proposed compost/organic soil amendments should be utilized in the selection of the material and in determination of proper loading rates for erosion control and the enhancement of vegetative cover. Total N and P rates within an erosion control system should be based on projected nutrient release to provide available N and P to maximize erosion control, yet reduce nutrient loss under runoff events. This more conservative approach, such as increasing the wood chip to compost ratio, will minimize offsite losses of N and P during initial establishment, but more importantly, will limit long-term losses of these nutrients as organically bound fractions are released through mineralization.

Finally, additional data should be collected to further evaluate DMC as an erosion control treatment. To compensate for the delay in runoff from the ECC treatment under vegetated conditions, the study methodology should be modified to expose the sediment bed to a fixed duration of rainfall, collect runoff for the duration of the rainfall and in addition, collect runoff sub-samples at set time intervals during the event. This modification will determine changes, if any, in the loss of sediment and/or nutrients over time and allow for the comparison of runoff constituents from the entire rainfall event.

LIMITATIONS OF THE STUDY DESIGN

(Information below provided by reviewers at the Texas Commission on Environmental Quality)

"The design of this study provided for the experimental plots to be subjected to rainfall of uniform intensity but varying duration. The average duration of rainfall exposure for the compost treatments was substantially greater than for the control treatments. This study does not provide a basis for predicting the relative performance of the two treatments in any single, defined rainfall event or in any representative set of rainfall events.

The results of this study raise concerns about the potential release of nutrients from erosion control compost (ECC) containing 50% composted manure in extended, high-intensity storms. However, the substantial difference in average duration of rain exposure experienced by the treatments limits the use of the study results in evaluating the probable effects of using this treatment as an alternative to the control treatment – either in regard to erosion control or in regard to nutrient loadings in runoff. Neither does it provide a basis for recommending modifications of the ECC treatment. Such evaluation will require, at a minimum, the testing of the recommended modifications of the ECC treatment alongside treatments using the current ECC specifications. Because of these design limitations, the Texas Commission on Environmental Quality cannot apply the information and conclusions described in this study about the performance of the two treatments to water quality management practices.

Conclusive evaluation of the use of composted manure as a water quality management tool – comparing its average life-cycle rate of release of nutrients in particular applications with that of control treatments – will require either an extended outdoor field trial or sequential testing with multiple simulated rainfall events on the same set of plots in a representative set of rain events until the soil nutrient concentrations in the compost-treated plots fall within agronomic levels."

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