EFFECTS OF COMPOSTED DAIRY MANURE ON SOIL CHEMICAL PROPERTIES AND FORAGE YIELD AND NUTRITIVE VALUE OF COASTAL BERMUDAGRASS [*Cynodon dactylon* (L.) Pers.]

A Thesis

by

THOMAS J HELTON

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

MASTER OF SCIENCE

December 2004

Major Subject: Soil Science

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Approved as to style and content by:

Mark L. McFarland (Co-Chair of Committee)	Frank M. Hons (Co-Chair of Committee)
James P. Muir (Member)	Saqib Mukhtar (Member)

Mark A. Hussey
(Head of Department)

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ABSTRACT

Effects of Composted Dairy Manure on Soil Chemical Properties and Forage Yield and Nutritive Value of Coastal Bermudagrass [*Cynodon dactylon* (L.) Pers.].

(December 2004)

Thomas J Helton, B.S., Texas A&M University

Co-Chairs of Advisory Committee: Dr. Mark L. McFarland
Dr. Frank M. Hons

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 [*Cynodon dactylon* (L.) Pers.] yield and nutritive value. Composted dairy manure was surface applied at rates of 14 (125 kg N ha^{-1}), 29 (250 kg N ha^{-1}) and 57 (500 kg N ha^{-1}) Mg dry matter (DM) ha^{-1}, and raw dairy manure was surface applied at a rate of 54 (420 kg N ha^{-1}) Mg DM ha^{-1} to established bermudagrass. Selected compost and manure plots received supplemental inorganic N at rates of 56, 84 and 112 kg ha^{-1} $cutting^{-1}$ or 112 kg ha^{-1} $cutting^{-1}$ of supplemental N with supplemental inorganic phosphorus or potassium at rates of 112 kg P_2O_5 ha^{-1} yr^{-1} and 112 kg K_2O ha^{-1} $cutting^{-1}$, respectively.

Composted dairy manure (29 and 57 Mg DM 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 (29 and 57 Mg DM 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 NH_4, NO_3, 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.

DEDICATION

I dedicate this thesis to the two people that have had the greatest influence on my life, my parents, Tommy and Brenda Helton. They have always placed the highest expectations on me and for that I am forever grateful. They showed me a world that has endless opportunities and that through God all things are possible. I am forever in your debt for the numerous sacrifices both of you have made throughout the years to help me achieve my goals and dreams. Thank you for your unconditional love and support that has inspired me to be who I am today.

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From the bottom of my heart I would like to express my thanks and gratitude to Elisha, my best friend and future wife, for all of her love, support and understanding during this journey.

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CHAPTER I

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 manure application too many fields associated with livestock facilities has resulted in the accumulation of some nutrients to levels far above crop requirements, and in some cases, exceeding regulatory thresholds for P (Ferguson and Nienaber, 2000; Nair and Graetz, 2002; Pierzynski and Logan, 1993; Sharpley and Withers, 1994). Several factors have contributed to this problem. Average herd size has increased dramatically over the last 20 years and much of the animal feed must be imported since on-farm production is no longer sufficient to support the herd (Fleming, 2004; Sanderson and Jones, 1997). The ratio of feed nutrient import to export is large, resulting in a net nutrient surplus on both a farm and watershed basis (Klausner et al., 1998; Sanderson and Jones, 1997). Manures are expensive to transport because they generally have high moisture content (50-80%) and low nutrient concentrations compared to inorganic fertilizer. In addition, the narrow N:P ratio in cattle manure often results in excess loading of P when application rates are based on crop N demands (Dao, 1999). In some cases, improper manure management and disposal of manure at high application rates also have been contributing factors. As a result, voluntary and regulatory efforts have been made to include P restrictions on manure applications to agricultural fields.

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

The dairy industry in north central Texas faces significant environmental challenges related to management of livestock manure generated by concentrated animal feeding operations. Rapid growth during the 1980’s made Erath County a major milk-producing county, which currently has over 41,000 dairy cows (Fleming, 2004; TNRCC, 2001). At the same time, operations in this watershed shifted from relatively small dairies to large, concentrated animal feeding operations. The North Bosque River was included on the Texas Clean Water Act (CWA) 303(d) List in 1998 and identified as impaired under narrative water quality standards related to nutrients and aquatic plant growth (TNRCC, 2001). Subsequently, two P TMDLs were prepared and adopted by the Texas Commission on Environmental Quality (TCEQ) for Segments 1226 and 1255 of the North Bosque River.

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. Other issues affecting the marketability of manure for land application are nuisance odor, pathogen concerns, insect larvae and viable weed seed content (Horn et al., 1994).

One proposed strategy to address problems associated with manure management that has attracted the attention of farmers, waste-generators, public officials and environmentalists is composting (Rynk et al., 1992). Composting manure produces a product that is more easily handled and stored because it reduces the total weight and volume of the material. Compost also has low odor and temperatures reached during the composting process kill most pathogens and viable weed seeds (Eghball and Power, 1999a). Like raw manure, compost can improve soil physical and chemical properties by increasing organic matter while providing plant nutrients (DeLuca and DeLuca, 1997). However, the effects of composting on release rates and plant availability of nutrients contained in manure are not well understood. This information is essential to determine proper application rates of compost and the need for supplemental fertilizer so that compost use may be both economical and environmentally sound.

Literature Review

Composting is the microbially-mediated aerobic decomposition of organic materials under reasonably controlled conditions. During this biological process, thermophillic, aerobic microorganisms convert organic material into a stable humus-like product (Leonard, 2001). Microorganisms use the organic carbon, nutrients and water as a source of energy and nutrition for growth thus breaking down the organic matter (Beegle, 1997). During the composting process, carbon dioxide, water vapor and heat from microbial respiration are released into the air. Finished compost is a more stable product made up of microbial residues and the more resistant organic compounds from the raw materials. Water and carbon dioxide loss during the process significantly reduce the volume and weight of the finished product. Schlegel (1992) reported that composting reduced the moisture content of manure from about 80% in fresh manure to 20 to 25% in compost, which decreased the amount of material to be transported and related costs. Properly composted manure also has no objectionable odor and has more desirable physical properties (loose, friable texture with more uniform particle size) than fresh manure.

Composting typically changes the concentrations and plant availability of nutrient elements contained in manure, particularly N. The amount of N lost during the composting process depends, in part, on the carbon (C):N ratio of the compost mixture (DeLuca and DeLuca, 1997). The optimal C:N ratio for effective composting ranges from 25-30:1, although initial C:N ratios from 20:1 to 40:1consistently produce good results (Rynk et al., 1992). If the C:N ratio of compost is too low, excess N can be lost to the atmosphere as ammonia or nitrous oxide. Loss of N can lead to several problems such as increased odor, reduced fertilizer value of the compost, and ammonia-laden environments that are corrosive to machines and buildings, and can compromise respiratory health (Leonard, 2001). In contrast, high C:N ratios can result in net immobilization of N and may slow or prevent compost maturation (Rynk et al, 1992; Leonard, 2001).

Eghball et al. (1997) reported a 19.3 to 42.5% loss of initial manure N during composting of beef cattle feedlot manure. Ammonia volatilization (calculated by difference) accounted for more than 92% of the N lost. Approximately 30 to 40% of the N in raw dairy manure is in the ammonium form, or in compounds, such as urea, that readily convert to ammonium N (Beegle, 1997). In comparison to raw manures, more of the N in composted manures exists in stable organic forms, thus N losses are minimized during storage, delivery and surface application (Paul and Beauchamp, 1993; DeLuca and DeLuca, 1997). Other potential losses of N, potassium (K) and to a lesser extent P from composting piles include runoff and leaching, which are highly variable and largely controlled by site-specific environmental (temperature and rainfall) and management factors (Eghball et al., 1997).

Nutrient release rates, particularly N, and plant availability are critical issues in determining appropriate rates of application of organic soil amendments such as compost. However, mineralization of organic materials depends on several factors that vary from year to year, including temperature, moisture, organic matter composition, and soil/organic matter contact (Eghball, 2002). The N pools in composted manure are different from those contained in non-composted manure (Eghball, 2000). Most of the readily mineralizable N in composted manures has already been converted to inorganic forms while the remaining organic N is in more stable N pools.

Eghball and Power (1999a) reported that first year N availability was approximately 20% for compost and 38% for manure in both conventional and no-till systems. However, total N use efficiency from compost was only 12% during this four-year study, compared to 17% for manure and 45% for inorganic fertilizer. In a similar study, Eghball and Power (1999b) reported that estimated N availability was 15% and 40% for compost and manure, respectively, in the first year and 8% and 18% in the second year. Greenhouse experiments by Castellanos and Pratt (1981) showed that composted dairy manure (20.1 g kg^{-1} average N concentration) provided about 50% as much available N as non-composted dairy manure (24.3 g kg^{-1} average N concentration).

Soil type also can affect nutrient recovery. Nitrogen uptake by corn from composted and fresh cow manure was not different on a Chicot sandy clay loam soil, but was significantly greater from fresh cow manure on St. Benoit sandy loam soil (Xie and MacKenzie, 1986). However, corn yields were not different for either soil type.

In an incubation study, Hadas and Portnoy (1994) reported that inorganic N release into soil from three different cattle manure composts and an earthworm humus over 32 weeks ranged from 11 to 29 % of total N. Of that amount, 2 to 12% was initially inorganic N, and 1 to 5% was soluble organic N. However, net mineralization rates of insoluble organic N generally did not exceed 10% of total N. Similar rates of N mineralization from composted dairy manure-amended samples were reported by Castellanos and Pratt (1981) during a 10-week incubation study. Eghball (2000) determined that of the organic N applied the previous autumn, 11% was mineralized from composted beef cattle manure compared to 21% from noncomposted manure during the following growing season. Nitrogen mineralization rates for compost and manure were similar to the reported values above for no-till and conventional till systems even though compost and manure were surface-applied in the no-till plots. Low N mineralization rates from compost can be attributed to the fact that most of the easily convertible N is lost during composting and remaining N is in a more stable form (Eghball et al., 1997; Eghball, 2000).

Ferguson and Nienaber (1995) reported application of beef feedlot manure and composted feedlot manure produced corn silage yields similar to inorganic fertilizer. Eghball and Power (1999b) reported annual or biennial manure or compost application resulted in corn grain yield similar to the fertilizer treatment. Schlegel (1992) reported that grain yield of irrigated grain sorghum increased by 377 kg ha^{-1} for each 2.24 Mg

ha^{-1} of applied compost, and was equivalent to the increase from 13.4 kg ha^{-1} of inorganic N fertilizer. Treatments combining composted manure and N fertilizer produced greater grain yields than either amendment alone. Sorghum yields were increased by 502, 1254, 1254, and 960 kg ha^{-1} in 1987-1990, respectively, with a combination treatment compared to either compost or N alone. In addition, compost alone had no effect on soil nitrate levels to a depth of 3 m either year, but soil P, K and organic matter (OM) in the 0-15 cm zone increased linearly with increasing compost rates.

One of the major concerns facing agriculture is proper management of P inputs. In areas close to confined livestock production, manures are generally applied to agricultural fields at rates to meet crop N requirements and avoid groundwater quality problems created by leaching excess N (Sharpley, 1996). Manure or compost application based on crop N requirements can greatly increase soil P levels because the N:P ratios in most manures and composts are more narrow than the N:P uptake ratios of most crops. These practices have led to P accumulation in the soil that is more of an environmental concern than an agronomic one. Eutrophication in surface freshwater is often controlled by P inputs, because natural air-water exchange of N and C and fixation of atmospheric N by certain blue-green algae provide an adequate N supply. Excessive eutrophication restricts water use for recreation, industry, and drinking due to increased growth of undesirable algae and aquatic weeds, which by their senescence and decay, can cause oxygen shortages and fish kills (Sharpley and Withers, 1994).

When manure application rates are based on P instead of N, farmers are forced to find alternative ways of disposing of excess manure and often must apply some supplemental fertilizer to achieve optimum crop yields (Sharpley and Withers, 1994). Schlegel (1992) reported that manure compost can be effective for maintaining or increasing soil chemical levels, especially P, without excessive accumulation of NO_3^-, but should be applied with N fertilizer for optimum grain production. Eghball and Gilley (1999) found that P-based manure and compost applications, with supplemental N, had acceptable runoff P loss and dissolved P constituted 91% of the bioavailable P in runoff. Phosphorus-based beef cattle feedlot manure or compost applications with supplemental inorganic N had similar corn grain yields to N-based treatments and inorganic fertilizer applications, but had significantly less soil-available P after 4 years (Eghball and Power, 1999b). When application rate was based on correct N or P availability, manure and compost produced corn grain yields equal to or greater than inorganic fertilizer. However, they recommend that P-based manure or compost applications be used on sites vulnerable to P runoff loss, while N-based applications may be used in areas where the potential for P runoff loss is minimal.

CHAPTER II

EFFECTS OF COMPOSTED DAIRY MANURE ON SOIL CHEMICAL PROPERTIES AND FORAGE YIELD AND NUTRITIVE VALUE OF COASTAL BERMUDAGRASS

Objectives

The objectives of this research were to compare the effects of dairy manure compost and raw dairy manure alone, or in combination with supplemental inorganic fertilizer, on soil chemical properties and Coastal bermudagrass yield and nutritive value.

Materials and Methods

Site Descriptions

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 (N 32° 15’, W 98° 12’, altitude 395 m) in 2002 and 2003. The soil type is a May fine sandy loam (fine-loamy, mixed, thermic, Udic Haplustalfs) with 0-1% slope (USDA, 1973). Soil in the upper 15 cm was initially 650 g kg^{-1} sand, 260 g kg^{-1} silt, 90 g kg^{-1} clay, 13.9 g kg^{-1} organic carbon and had a pH of 4.6. Soil in the 15 to 30-cm depth was 570 g kg^{-1} sand, 240 g kg^{-1} silt, 190 g kg^{-1} clay, 7.5 g kg^{-1} organic carbon and had a pH of 5.6.

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. Dairy manure compost was applied at 3 rates to supply N at 125 (14 Mg DM ha^{-1}), 250 (29 Mg DM ha^{-1}) and 500 (57 Mg DM ha^{-1}) kg total N ha^{-1}. Dairy manure was applied at a single rate of 420 (54 Mg DM ha^{-1}) kg total N ha^{-1}. Selected compost and manure plots received supplemental inorganic N at rates of 56, 84 and 112 kg N ha^{-1} $cutting^{-1}$. In addition, selected compost and manure plots receiving 112 kg N ha^{-1} $cutting^{-1}$ also received supplemental P at a rate of 112 kg P_2O_5 ha^{-1} yr^{-1} applied at spring green-up or supplemental K at 112 kg K_2O ha^{-1} $cutting^{-1}$. An inorganic fertilizer treatment based on soil test recommendations (112 kg N ha^{-1} $cutting^{-1}$, 112 kg P_2O_5 ha^{-1} yr^{-1}, 112 kg K_2O ha^{-1} $cutting^{-1}$) and an unfertilized check also were included. Inorganic N, P and K sources were ammonium nitrate (34-0-0), triple superphosphate (0-46-0), and potassium chloride (0-0-60), respectively. 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 Mg ha^{-1}) treatments, which were applied annually. A summary of all treatments applied is provided in Table 1, and manure and compost chemical characteristics are presented in Table 2.

Table 1. Treatment summary.

Treatment	Rate	Supplemental Inorganic Fertilizer N	Supplemental Inorganic Fertilizer P_2O_5	Supplemental Inorganic Fertilizer K_2O
	Mg ha^{-1}	kg ha^{-1} $cutting^{-1}$	kg ha^{-1} yr^{-1}	kg ha^{-1} $cutting^{-1}$
Compost (C1)	14	56	—	—
Compost (C1)	14	112	—	—
Compost (C2)	29	—	—	—
Compost (C2)	29	56	—	—
Compost (C2)	29	84	—	—
Compost (C2)	29	112	—	—
Compost (C2)	29	112	112	—
Compost (C2)	29	112	—	112
Compost (C3)	57	—	—	—
Compost (C3)	57	56	—	—
Compost (C3)	57	84	—	—
Compost (C3)	57	112	—	—
Compost (C3)	57	112	112	—
Compost (C3)	57	112	—	112
Manure (M)	54	—	—	—
Manure (M)	54	56	—	—
Manure (M)	54	84	—	—
Manure (M)	54	112	—	—
Manure (M)	54	112	112	—
Manure (M)	54	112	—	112
Untreated Check (UC)	—	—	—	—
		Soil Test Recommendation		
Inorganic Fertilizer (IF)	—	112	112	112

Table 2. Chemical analysis of raw dairy manure and composted dairy manure.

Parameter	Raw Dairy Manure	Composted Dairy Manure
Dry Matter (%)	63	79
Nitrogen ($g\ kg^{-1}$)	7.1	8.6
Carbon ($g\ kg^{-1}$)	93	84
Phosphorus ($g\ kg^{-1}$)	1.9	3.9
Potassium ($g\ kg^{-1}$)	13	23
Calcium ($g\ kg^{-1}$)	17	39
Magnesium ($g\ kg^{-1}$)	2.1	4.1
Sodium ($g\ kg^{-1}$)	5.1	5.2
Zinc ($mg\ kg^{-1}$)	57	112
Iron ($mg\ kg^{-1}$)	163	278
Copper ($mg\ kg^{-1}$)	19	24
Manganese ($mg\ kg^{-1}$)	136	208

Data Collection and Analysis

Background soil samples were collected from the site in March 2002 to determine soil physical and chemical properties and to generate fertilizer recommendations (Table 3). Twenty soil cores were collected randomly across the study site at depths of 0 to 15 cm and 15 to 30 cm. In addition, 20 soil cores were collected at depths of 0 to 5, 5 to 15 and 15 to 30 cm from each plot at the end of the first and second growing seasons to determine treatment effect on selected soil parameters. Soil sampling dates were February 10-11 and November 11-12, 2003. Soil samples were obtained using a stainless steel sampling probe (1.9-cm I.D.). Samples were oven-dried at 65°C, ground to pass a 2-mm sieve and analyzed for pH (1:2 soil: deionized water; Schofield and Taylor, 1955), electrical conductivity (EC) (Rhoades, 1982), soil organic carbon (OC) according to Giovannini et al. (1975), but modified to include; fine grinding to pass a 100 mesh sieve, and a temperature of 650°C, textural analysis (Day, 1965) (background samples only), NO_3-N (1 M KCl extraction; modified Keeney and Nelson, 1982), and extractable P, K, Ca, Mg, Na and S (1.4 M NH_4OAc and 0.025 M EDTA, pH 4.2; Hons et al., 1990) by the Texas Cooperative Extension Soil Testing Laboratory (College Station, TX). End-of-season samples from the 0 to 5 and 5 to 15-cm depth also were analyzed for NH_4 (modified Keeney and Nelson, 1982), soil organic carbon (as described above), and Fe, Zn, Mn and Cu (0.005 M DTPA, 0.01 M $CaCl_2$, 0.1 M TEA, pH 7.2; Lindsay and Norvell, 1978).

Table 3. Soil test analysis for background sample collected in March 2002.

Parameter	0-15 cm	15-30 cm
pH	4.6	5.6
	$mg\ kg^{-1}$	
NO_3	4	4
P	11	1
K	86	127
Ca	431	1402
Mg	61	191
Zn	0.4	0.1
Fe	73	10
Mn	42	7
Cu	0.5	0.5
Na	265	218
S	32	22

Samples of the dairy manure compost and raw dairy manure were collected at the time of application to determine chemical characteristics. Three subsamples were obtained by collecting a minimum of ten grab samples from an 8-m^3 stockpile purchased for the study. Samples were analyzed in the Texas Cooperative Extension (TCE; College Station, TX) laboratory on a dry weight basis. Total N (TKN; colorimetric measurement using a Technicon Auto Analyzer II), P, K, Ca, Mg, Na, Zn, Fe, Cu, and Mn (Inductively Coupled Argon Plasma (ICP) spectrometry analysis) were determined using a modified Kjeldahl digestion procedure (Nelson and Sommers, 1980). The C:N ratio of manure and compost was determined using an Elementar Vario Max CN elemental analyzer (Elementar Americas, Inc., NJ). Compost and manure treatments were applied based on initial nutrient and moisture analysis and were not corrected for N availability or N volatilization losses from the manure.

All plots were harvested on approximately 28-day intervals using an ALMACO forage harvester (ALMACO; Nevada, IA) to cut a 1.32- by 6-m swath from the center of each plot. This allowed for 0.84-m buffers on either side of the swath as well as 1.32-m buffers on either end of the swath to minimize edge effect. Field plots were harvested four times each in 2002 and 2003. Harvest dates in 2002 were May 16, June 14, July 15 and October 2. Harvest dates in 2003 were May 19, June 18, July 17 and September 25.

Forage sub-samples were collected from each plot for laboratory analysis, oven-dried at 65°C, weighed, ground (0.5-mm sieve) and analyzed to determine moisture content, crude protein (Sheldrick, 1986), and acid detergent fiber (ADF) (Komarek, 1993). Nutrient concentrations were determined by ICP spectrometry analysis of samples following a nitric acid digest (Feagley et al., 1994). Forage samples were analyzed in the TCE laboratory.

The difference method was used to estimate apparent nutrient recovery of inorganic fertilizer using the following equation:

Apparent inorganic fertilizer recovery (AFR) =

$$\frac{\text{Inorganic fertilizer nutrient (IF) uptake - Untreated check (UC) uptake}}{\text{Inorganic fertilizer nutrient applied}} \text{ X } 100$$

A modified difference method was used to determine the apparent compost or manure nutrient recovery:

Apparent compost or manure nutrient recovery (%) =

$$\frac{\text{Treatment uptake – (UC uptake + (IF applied x AFR / 100))}}{\text{Total amount of nutrient applied from compost or manure}} \text{ X } 100$$

Data were analyzed by PROC GLM modified for repeated measures analysis in statistical analysis system (SAS Inst.) to determine analysis of variance (ANOVA), and means separated using Fisher’s protected least significant difference (LSD) method at the 0.05 significance level.

Results and Discussion

Rainfall data for 2002 and 2003 along with 5, 10, 50 and 100-year averages are presented in Table 4. In 2002, total rainfall (930 mm) was 21% above the long-term average (768 mm). Rainfall in March and May of 2002 was 237 and 168%, respectively, of the long-term average for those months. In 2003, total rainfall (713 mm) was 93% of the long-term average, but was reasonably well distributed throughout the growing season.

Forage Yield

There was a year by treatment interaction for forage yield. Individual harvest (H1-H4) values represent the mean of three replications, while cumulative yields are totaled across harvests. Cumulative yields were compared where no interactions occurred among treatments and harvest dates using repeated measures analysis. Where treatment by harvest interactions were observed, means within a harvest were analyzed.

Without supplemental inorganic fertilizer, dairy manure compost applied at rates of 29 (C2) and 57 (C3) Mg ha^{-1} and raw dairy manure (M) applied at 54 Mg ha^{-1} produced cumulative forage yields significantly greater than the untreated check in both years of the study (Table 5). Eghball and Power (1999b) reported similar results for annual or biennial beef feedlot manure or compost applied to corn, and showed increased grain yield in all 4 yr compared to the unfertilized check. However, inorganic fertilizer (IF) produced cumulative forage yields greater than either rate of compost and dairy manure in both years. In contrast, Ferguson and Nienaber (1995) found that

Table 4. Rainfall data for Stephenville, Texas.

	January	February	March	April	May	June	July
				mm			
2002	27	35	116	50	198	80	76
2003	15	81	38	74	76	155	15
Averages							
5 year	36	75	65	80	93	99	26
10 year	32	67	68	69	105	93	57
50 year	39	51	50	82	114	81	59
100 year	41	47	49	81	118	76	54

	August	September	October	November	December	Annual
				mm		
2002	5	57	164	20	102	929
2003	85	99	44	21	9	713
Averages						
5 year	37	62	80	53	51	702
10 year	66	74	85	60	52	810
50 year	57	75	86	47	45	780
100 year	56	70	77	54	46	768

Table 5. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone compared to untreated check on Coastal bermudagrass yields.

	2002				
	Yield				
Treatment†	H1	H2	H3	H4	Cumulative
	kg ha $^{-1}$				
C2	2,448	1,723	2,967	2,643	9,781 b‡
C3	3,503	2,275	3,166	2,899	11,844 b
M	2,847	1,951	3,283	2,646	10,727 b
IF	4,274	3,327	4,367	4,088	16,056 a
UC	1,451	932	2,323	1,871	6,577 c
					***
	2003				
	kg ha $^{-1}$				
C2	3,418	2,320	2,290	2,646	10,674 b‡
C3	3,671	2,374	2,511	2,785	11,342 b
M	4,140	2,571	2,969	3,250	12,931 b
IF	5,915	3,793	4,380	5,064	19,153 a
UC	2,505	1,520	1,574	1,557	7,156 c
					***

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

annual application of beef feedlot manure and composted feedlot manure produced corn silage yield similar to commercial fertilizer application. Eghball and Power (1999b) also reported corn grain yields from annual or biennial manure or compost applications were similar to the inorganic fertilizer treatment. Cumulative yields for C2 and C3 ranged from 9,781 to 11,844 kg DM ha^{-1} and were not different from the dairy manure treatment (M) in either year. Sanderson and Jones (1997) reported dry matter yield of Coastal bermudagrass increased linearly each year as the rate of manure-supplied N increased. These data indicate that a single compost application at rates of 29 and 57 Mg ha^{-1} and dairy manure applied at 54 Mg ha^{-1} on Coastal bermudagrass cannot provide nutrients at levels sufficient to produce yields comparable to those obtained using inorganic fertilizer.

There was a N rate by compost or manure rate interaction on forage yields in both years. To examine this interaction, compost and manure rates were evaluated within each N rate and year. In 2002, supplemental inorganic fertilizer was applied to compost and manure treatments only for harvests 2-4; thus, treatment comparisons in that year are restricted to those harvest dates.

In 2002, application of supplemental inorganic N at 56 kg ha^{-1} $cutting^{-1}$ to the manure (M) treatment produced yields that were significantly greater than those in the IF treatment for the second harvest, and a similar trend was observed for harvest 4 although differences were not significant (Table 6). Compost at the highest rate (C3, 57 Mg ha^{-1}) with supplemental N (56 kg N ha^{-1}) produced yields equal to IF for all three harvests in 2002 and a similar result was observed for the 29 Mg ha^{-1} (C2) rate of compost for

Table 6. Effects of dairy manure compost and raw dairy manure with supplemental N at 56 kg ha^{-1} cutting^{-1} compared to inorganic fertilizer alone on Coastal bermudagrass yields.

	2002				
	Yield				
Treatment†	H1	H2	H3	H4	Cumulative
	kg ha^{-1}				
C1	—	2,542 d‡	3,723 b	3,345 b	9,610
C2	—	2,990 c	4,267 a	4,505 a	11,762
C3	—	3,563 ab	4,467 a	3,446 b	11,475
M	—	3,740 a	4,433 a	4,607 a	12,779
IF	—	3,327 b	4,367 a	4,088 ab	11,782
		***	*	*	

	2003				
	kg ha^{-1}				
C1	5,389	3,907	3,835	4,398	17,530‡
C2	5,717	4,128	4,215	4,599	18,657
C3	5,927	4,224	4,277	4,792	19,219
M	6,058	3,961	4,273	4,981	19,274
IF	5,915	3,793	4,380	5,064	19,153
					NS

†Abbreviations: C1, compost 14 Mg ha^{-1}; C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

harvests 3 and 4. Even with supplemental N, the low rate of compost (C1, 14 Mg ha^{-1}) produced significantly lower yields than IF and other treatments for most harvests. In contrast, in 2003 supplemental fertilizer applied at 56 kg N ha^{-1} $cutting^{-1}$ to all three rates of compost and raw manure produced cumulative yields that were not different from each other or the inorganic fertilizer (IF) treatment. Cumulative forage yields for compost and manure treatments in 2003 ranged from 17,530 to 19,274 kg DM ha^{-1} compared to 19,153 kg DM ha^{-1} for IF.

Application of 84 kg ha^{-1} $cutting^{-1}$ of supplemental N to compost or manure plots produced cumulative forage yields that were not different from IF in either 2002 or 2003 (Table 7). A similar response was observed in 2002 when 112 kg N ha^{-1} $cutting^{-1}$ was applied to the three rates of compost and manure (Table 8). However, when 112 kg N ha^{-1} was applied to C3 and M in 2003 yields were significantly greater than IF in the first harvest, and C3 yields were greater than all other treatments at harvest 2. Early season availability of greater amounts of supplemental nutrients mineralized from these organic treatments likely promoted improved plant growth. Schlegel (1992) reported that composted manure with inorganic fertilizer resulted in greater grain sorghum yield than either source applied alone. In contrast, Jokela (1992) reported inorganic N application at 56, 112 and 168 kg ha^{-1} to plots that received manure at 9 Mg ha^{-1} did not significantly increase corn yields compared to manure alone.

To further evaluate the effects of supplemental N on bermudagrass yields, statistical comparisons were made among N rates and IF within each compost and manure rate. Application of N at 56 kg N ha^{-1} $cutting^{-1}$ to the C1 (14 Mg ha^{-1}) treatment

Table 7. Effects of dairy manure compost and raw dairy manure with supplemental N at 84 kg ha^{-1} $cutting^{-1}$ compared to inorganic fertilizer alone on Coastal bermudagrass yields.

	2002				
	Yield				
Treatment†	H1	H2	H3	H4	Cumulative
	kg ha^{-1}				
C2	—	3,555	4,535	4,801	12,890‡
C3	—	3,629	4,800	4,348	12,776
M	—	4,016	4,797	5,186	13,999
IF	—	3,327	4,367	4,088	11,782
					NS
	2003				
	kg ha^{-1}				
C2	6,306	4,196	4,568	5,298	20,368‡
C3	6,522	4,531	4,577	5,618	21,248
M	6,414	4,279	4,541	5,317	20,550
IF	5,915	3,793	4,380	5,064	19,153
					NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha-1; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 8. Effects of dairy manure compost and raw dairy manure with supplemental N at 112 kg ha^{-1} cutting^{-1} compared to inorganic fertilizer alone on Coastal bermudagrass yields.

2002

Treatment†	H1	H2	H3	H4	Cumulative
	Yield				
	kg ha^{-1}				
C1	—	3,443	4,557	4,020	12,019‡
C2	—	3,524	4,736	4,081	12,341
C3	—	4,017	4,686	4,585	13,288
M	—	3,924	4,479	4,444	12,846
IF	—	3,326	4,367	4,088	11,782
					NS

2003

Treatment†	H1	H2	H3	H4	Cumulative
	kg ha^{-1}				
C1	5,839 c	4,245 b	4,632	4,693	19,409
C2	6,617 ab	4,160 b	4,605	4,746	20,129
C3	6,764 a	4,893 a	4,854	5,173	21,684
M	7,000 a	4,204 b	4,630	4,939	20,774
IF	5,915 bc	3,793 b	4,380	5,064	19,153
	*	**	NS	NS	

†Abbreviations: C1, compost 14 Mg ha$^{-1;}$ C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

produced cumulative yields that were significantly lower than IF and C1 with 112 kg N ha^{-1} $cutting^{-1}$ in 2002 (Table 9). A similar result was observed for this treatment in 2003 at the third harvest, and a similar trend was observed for harvests 1, 2 and 4 in that year. When 112 kg N ha^{-1} $cutting^{-1}$ was applied to the C1 treatment, yields were not different from IF in either year. Higher yields for all treatments at the first harvest in 2003 (5,389 to 5,915 kg DM ha^{-1}) indicated better growing conditions and possibly better near surface conditions for N mineralization.

When compost rate was increased to 29 Mg ha^{-1}, there were no differences among N rates from 56 to 112 kg ha^{-1} $cutting^{-1}$ or between these rates and IF in either 2002 or 2003 (Table 10). When compost was applied without supplemental N (C2), yields were significantly lower than all other treatments. A similar trend was observed for the high rate of compost (C3) in 2002 and 2003 (Table 11), although in 2003 C3 with 112 kg N ha^{-1} $cutting^{-1}$ produced greater yields than most treatments. Most importantly, there were no differences between yields for C3 and IF when as little as 56 kg ha^{-1} $cutting^{-1}$ of supplemental inorganic N was applied to compost.

In 2002, there were no differences in cumulative yields among N rates from 56 to 112 kg N ha^{-1} $cutting^{-1}$ when applied to 54 Mg ha^{-1} of manure (Table 12). Yields were similar to IF except for manure with 84 kg N ha^{-1} $cutting^{-1}$ which was significantly greater than IF. Similar results were observed in 2003, with the exception of greater yields for the 112 kg ha^{-1} N rate compared to the 56 kg N ha^{-1} in harvests 1

Table 9. Effects of composted dairy manure (14 Mg ha^{-1}) with two rates of supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

2002

Treatment†	N rate	H1	H2	H3	H4	Cumulative
		Yield				
		kg ha^{-1}				
C1	56	—	2,542	3,723	3,345	9,611 b‡
C1	112	—	3,443	4,557	4,020	12,019 a
IF		—	3,327	4,367	4,088	11,782 a
						**

2003

Treatment†	N rate	H1	H2	H3	H4	Cumulative
		kg ha^{-1}				
C1	56	5,389	3,907	3,835 b	4,398	17,530
C1	112	5,839	4,245	4,632 a	4,693	19,409
IF		5,915	3,793	4,380 a	5,064	19,153
		NS	NS	*	NS	

†Abbreviations: C1, compost 14 Mg ha^{-1}; N, 56 and 112 kg N ha^{-1} $cutting^{-1}$;
IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 10. Effects of composted dairy manure (29 Mg ha^{-1}) with four rates of supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

		2002				
		Yield				
Treatment†	N rate	H1	H2	H3	H4	Cumulative
		kg ha^{-1}				
C2	0	—	1,723	2,967	2,643	7,333 b‡
C2	56	—	2,990	4,267	4,505	11,762 a
C2	84	—	3,555	4,535	4,801	12,890 a
C2	112	—	3,524	4,736	4,081	12,341 a
IF		—	3,327	4,367	4,088	11,782 a
						**
		2003				
		kg ha^{-1}				
C2	0	3,418	2,320	2,290	2,646	10,674 b
C2	56	5,717	4,128	4,215	4,599	18,657 a
C2	84	6,306	4,196	4,568	5,298	20,368 a
C2	112	6,617	4,160	4,605	4,746	20,129 a
IF		5,915	3,793	4,380	5,064	19,153 a
						***

†Abbreviations: C2, compost 29 Mg ha^{-1}; N, (0, 56, 84 and 112 kg NH_4NO_3 ha^{-1} $cutting^{-1}$); IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 11. Effects of composted dairy manure (57 Mg ha^{-1}) with four rates of supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

		2002				
		Yield				
Treatment†	N rate	H1	H2	H3	H4	Cumulative
		kg ha^{-1}				
C3	0	—	2,276	3,166	2,899	8,342 b‡
C3	56	—	3,563	4,467	3,446	11,476 a
C3	84	—	3,629	4,800	4,348	12,776 a
C3	112	—	4,017	4,686	4,585	13,288 a
IF		—	3,327	4,367	4,088	11,782 a
						**
		2003				
		kg ha^{-1}				
C3	0	3,671	2,374	2,511	2,785	11,342 c‡
C3	56	5,927	4,224	4,277	4,792	19,219 b
C3	84	6,522	4,531	4,577	5,618	21,248 ab
C3	112	6,764	4,893	4,854	5,173	21,684 a
IF		5,915	3,793	4,380	5,064	19,153 b
						***

†Abbreviations: C3, compost 57 Mg ha^{-1}; N, (0, 56, 84 and 112 kg N ha^{-1} $cutting^{-1}$);
IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 12. Effects of raw dairy manure (54 Mg ha^{-1}) with four rates of supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

Treatment†	N rate	H1	H2	H3	H4	Cumulative
		2002				
		Yield				
		kg ha^{-1}				
M	0	—	1,951	3,283	2,646	8,015 c‡
M	56	—	3,740	4,433	4,607	12,779 ab
M	84	—	4,016	4,797	5,186	13,998 a
M	112	—	3,924	4,479	4,444	12,846 ab
IF		—	3,327	4,367	4,088	11,782 b
						***
		2003				
		kg ha^{-1}				
M	0	4,140 c	2,571 b	2,970 c	3,250 b	12,931
M	56	6,058 b	3,961 a	4,273 b	4,981 a	19,274
M	84	6,414 ab	4,279 a	4,541 ab	5,317 a	20,550
M	112	7,000 a	4,204 a	4,630 a	4,939 a	20,774
IF		5,915 b	3,793 a	4,380 ab	5,064 a	19,153
		***	**	***	***	

†Abbreviations: M, dairy manure 54 Mg ha^{-1}; N, (0, 56, 84 and 112 kg N ha^{-1} $cutting^{-1}$); IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

and 3. When manure was applied without supplemental N, yields were significantly lower than all other treatments in both years.

The need for supplemental K was evaluated by applying 112 kg K_2O ha^{-1} cutting^{-1} to compost and raw dairy manure treatments receiving 112 kg N ha^{-1} cutting^{-1} (Tables 13-15). When compost was applied at 29 Mg ha^{-1}, there was a significant response to K at the fourth harvest in 2002 and the third harvest in 2003, and a similar trend for the second and fourth harvests in 2003 (Table 13). In contrast, there was no apparent response to K in either year when compost was applied at 57 Mg ha^{-1} (Table 14). Greater yields in plots receiving compost for harvest 2 in 2003 were attributable to an N response. When supplemental K was applied to plots receiving manure, a response to K was observed for cumulative yields in 2002 and harvest 2 in 2003, with similar trends for harvest 3 and 4 in the second year (Table 15).

Supplemental inorganic phosphorus (P) applied at 112 kg P_2O_5 ha^{-1} cutting^{-1} did not improve bermudagrass yields in plots receiving compost at 29 or 57 Mg ha^{-1} or those receiving raw dairy manure at 54 Mg ha^{-1} in either year (Tables 16-18). Yield responses observed for compost plots (57 Mg ha^{-1}) compared to IF for harvests 2 and 3 in 2003 were attributable to an N response (Table 17).

Table 13. Effects of two rates of supplemental K applied to composted dairy manure (29 Mg ha^{-1}) receiving 112 kg ha^{-1} cutting^{-1} supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

		2002				
		Yield				
Treatment†	K_2O	H1	H2	H3	H4	Cumulative
		kg ha^{-1}				
C2	0	—	3,524‡	4,736 a	4,081 b	12,340
C2	112	—	3,465	4,871 a	5,089 a	13,424
IF		—	3,326	4,367 b	4,088 b	11,782
			NS	*	*	
		2003				
		kg ha^{-1}				
C2	0	6,617 a	4,160	4,605 b	4,746	20,129
C2	112	6,391 a	4,541	5,040 a	5,515	21,485
IF		5,915 b	3,793	4,380 b	5,064	19,153
		*	NS	*	NS	

†Abbreviations: C2, compost 29 Mg ha^{-1} + 112 kg N ha^{-1} cutting^{-1}; K, 0 and 112 kg K_2O ha^{-1} cutting^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 14. Effects of two rates of supplemental K applied to composted dairy manure (57 Mg ha^{-1}) receiving 112 kg ha^{-1} $cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

		2002				
		Yield				
Treatment†	K_2O	H1	H2	H3	H4	Cumulative
		kg ha $^{-1}$				
C3	0	—	4,017	4,686	4,585	13,287‡
C3	112	—	3,799	4,716	3,880	12,394
IF		—	3,326	4,367	4,088	11,782
						NS
		2003				
		kg ha $^{-1}$				
C3	0	6,764‡	4,893 a	4,854	5,173	21,684
C3	112	6,706	4,900 a	4,661	5,516	21,783
IF		5,915	3,793 b	4,380	5,064	19,153
		NS	*	NS	NS	

†Abbreviations: C3, compost 57 Mg ha^{-1} + 112 kg N ha^{-1} $cutting^{-1}$; K, 0 and 112 kg K_2O ha^{-1} $cutting^{-1}$; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 15. Effects of two rates of supplemental K applied to dairy manure (54 Mg ha^{-1}) receiving 112 kg ha^{-1} $cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

Treatment†	K_2O	H1	H2	H3	H4	Cumulative
		2002				
		Yield				
		kg ha^{-1}				
M	0	—	3,924	4,479	4,444	12,846 b‡
M	112	—	3,955	4,709	5,154	13,819 a
IF		—	3,326	4,367	4,088	11,782 c
						**
		2003				
		kg ha^{-1}				
M	0	7,000 a	4,204 b	4,630	4,939	20,774
M	112	7,043 a	4,674 a	4,992	5,571	22,280
IF		5,915 b	3,793 c	4,380	5,064	19,153
		*	***	NS	NS	

†Abbreviations: M, manure 54 Mg ha^{-1} + 112 kg N ha^{-1} $cutting^{-1}$; K, 0 and 112 kg K_2O ha^{-1} $cutting^{-1}$; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 16. Effects of two rates of supplemental P applied to composted dairy manure (29 Mg ha^{-1}) receiving 112 kg ha^{-1} $cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

		2002				
		Yield				
Treatment†	P_2O_5	H1	H2	H3	H4	Cumulative
		kg ha^{-1}				
C2	0	—	3,524	4,736	4,081	12,341‡
C2	112	—	3,680	4,842	4,546	13,067
IF		—	3,326	4,367	4,088	11,782
						NS
		2003				
		kg ha^{-1}				
C2	0	6,617	4,160	4,605	4,746	20,129‡
C2	112	6,440	4,313	4,688	4,689	20,131
IF		5,915	3,793 b	4,380	5,064	19,153
						NS

†Abbreviations: C2, compost 29 Mg ha^{-1} + 112 kg N ha^{-1} $cutting^{-1}$; P, 0 and 112 kg P_2O_5 ha^{-1} yr^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 17. Effects of two rates of supplemental P applied to composted dairy manure (57 Mg ha^{-1}) receiving 112 kg ha^{-1} $cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

		2002				
		Yield				
Treatment†	P_2O_5	H1	H2	H3	H4	Cumulative
		kg ha^{-1}				
C3	0	—	4,017	4,686	4,585	13,288‡
C3	112	—	3,825	4,986	4,538	13,349
IF		—	3,326	4,367	4,088	11,782
						NS
		2003				
		kg ha^{-1}				
C3	0	6,764‡	4,893 a	4,854 a	5,173	21,684
C3	112	7,008	4,802 a	4,823 a	5,636	22,269
IF		5,915	3,793 b	4,380 b	5,064	19,153
		NS	**	*	NS	

†Abbreviations: C3, compost 57 Mg ha^{-1} + 112 kg N ha^{-1} $cutting^{-1}$; P, 0 and 112 kg P_2O_5 ha^{-1} yr^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 18. Effects of two rates of supplemental P applied to dairy manure (54 Mg ha^{-1}) receiving 112 kg ha^{-1} $cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on Coastal bermudagrass yields.

				2002		
				Yield		
Treatment†	P_2O_5	H1	H2	H3	H4	Cumulative
			kg ha $^{-1}$			
M	0	—	3,924	4,479	4,444	12,846‡
M	112	—	3,910	4,742	4,937	13,590
IF		—	3,326	4,367	4,088	11,782
						NS
				2003		
			kg ha $^{-1}$			
M	0	7,000	4,204	4,630	4,939	20,774‡
M	112	6,425	4,235	4,392	5,227	20,278
IF		5,915	3,793	4,380	5,064	19,153
						NS

†Abbreviations: M, manure 54 Mg ha^{-1} + 112 kg N ha^{-1} $cutting^{-1}$; P, 0 and 112 kg P_2O_5 ha^{-1} yr^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Nutritive Value

There was a year by treatment interaction for tissue nutrient concentrations. Individual harvest (H1-H4) values represent the mean of three replications. Where no differences occurred among treatments and harvest dates using repeated measures analysis, nutrient concentrations were averaged across harvest dates for each year. Treatment by harvest interactions were evaluated by comparison of means within each harvest.

There was a N rate by compost or manure rate interaction on N concentration in Coastal bermudagrass tissue for both years. To further examine this interaction, compost and manure rates were evaluated within each N rate and year. Because supplemental fertilizer was applied to compost and manure treatments only for harvests 2-4 in 2002; treatment comparisons in that year were restricted to those harvest dates.

Tissue N concentrations in plots receiving dairy manure compost or raw dairy manure without supplemental fertilizer were significantly lower than IF for all harvests of both years (Table 19). Forage from untreated check plots had N concentrations that were undifferentiated from C2, C3 and M in six out of the eight harvests. These data and the yield data presented earlier indicate that compost and manure applied at these rates may need supplemental inorganic N to achieve forage yields and nutritive value levels similar to those obtained using inorganic fertilizer alone.

Likewise, the IF treatment (112 kg N ha^{-1}) produced tissue N concentrations which were greater than those in plots receiving compost or manure with 56

Table 19. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue N concentrations in Coastal bermudagrass.

Treatment†	H1	H2	H3	H4
	2002			
	g kg^{-1}			
C2	19 b‡	19 b	18 b	12 b
C3	21 b	19 b	17 b	12 b
M	19 bc	18 b	18 b	12 b
IF	25 a	26 a	22 a	15 a
UC	16 c	19 b	16 b	12 b
	**	**	*	*
	2003			
	g kg^{-1}			
C2	15 b	14 b	15 b	14 b
C3	15 b	15 b	15 b	14 b
M	15 b	15 b	15 b	15 b
IF	25 a	28 a	25 a	23 a
UC	14 b	13 c	15 b	14 b
	***	***	***	***

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** P $\leq$ 0.05, P $\leq$ 0.01 and P $\leq$ 0.001; NS = not significant; (Fishers Protected LSD).

kg N ha^{-1} in the second harvest of 2002 and all four harvests in 2003 (Table 20). A similar result was observed for the second harvest in 2002 and the third harvest in 2003, when 84 kg N ha^{-1} was applied to compost or manure plots (Table 21). However, when 112 kg N ha^{-1} of supplemental N was applied to compost or manure, tissue N concentrations were similar for most treatments in both years (Table 22).

To further examine the effects of supplemental N on tissue N concentrations in compost and manure amended plots relative to IF, comparisons were made among N rates within each compost and manure rate. Application of supplemental N at 84 or 112 kg ha^{-1} $cutting^{-1}$ to treatment C2 produced tissue N concentrations similar to IF for all harvests in 2002 (Table 23). Compost alone or with 56 kg N ha^{-1} $cutting^{-1}$ of supplemental N produced tissue N concentrations lower than those in IF at the second harvest and a similar trend was observed for harvest four of 2002. In 2003, C2 alone or with 56 kg N ha^{-1} $cutting^{-1}$ had lower tissue N concentrations than IF for all four harvests. In addition, tissue N concentrations for C2 with 84 kg N ha^{-1} were lower than IF in harvest 1, 2 and 3.

Similar results were observed for tissue N concentrations when supplemental N was applied to C3 and M (Tables 24 and 25, respectively). In general, C3 and M with 56 kg N ha^{-1} $cutting^{-1}$ of supplemental N produced tissue N concentrations that were greater than compost alone, but were less than IF in both years. However, when supplemental N was applied to raw dairy manure (M) there were no differences in tissue N concentration among any of the treatments for the third and fourth harvests of 2002 (Table 25).

Table 20. Effects of dairy manure compost and raw dairy manure with supplemental N at 56 kg ha^{-1} $cutting^{-1}$ compared to inorganic fertilizer alone on tissue N concentrations in Coastal bermudagrass.

Treatment†	H1	H2	H3	H4
2002				
	g kg^{-1}			
C1	——	22 b‡	21	14
C2	——	22 b	20	14
C3	——	22 b	20	15
M	——	23 b	22	14
IF	——	26 a	22	15
		**	NS	NS
2003				
	g kg^{-1}			
C1	16 b	20 b	20 b	19 b
C2	18 b	22 b	20 b	20 b
C3	17 b	20 b	19 b	20 b
M	18 b	26 a	20 b	20 b
IF	25 a	28 a	25 a	23 a
	***	**	*	*

†Abbreviations: C1, compost 14 Mg ha^{-1}; C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 21. Effects of dairy manure compost and raw dairy manure with supplemental N at 84 kg ha^{-1} $cutting^{-1}$ compared to inorganic fertilizer alone on tissue N concentrations in Coastal bermudagrass.

Treatment†	H1	H2	H3	H4
	2002			
	g kg^{-1}			
C2	——	23 bc‡	21	15
C3	——	22 c	21	16
M	——	24 b	23	15
IF	——	26 a	22	15
		**	NS	NS
	2003			
	g kg^{-1}			
C2	21	25	22 b	21
C3	21	25	22 b	20
M	22	26	24 ab	22
IF	25	28	25 a	23
	NS	NS	*	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha-1; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1});

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** P $\leq$ 0.05, P $\leq$ 0.01 and P $\leq$ 0.001; NS = not significant; (Fishers Protected LSD).

Table 22. Effects of dairy manure compost and raw dairy manure with supplemental N at 112 kg ha^{-1} $cutting^{-1}$ compared to inorganic fertilizer alone on tissue N concentrations in Coastal bermudagrass.

Treatment†	H1	H2	H3	H4
2002				
	g kg⁻¹			
C1	——	25 a‡	24 a	16
C2	——	24 ab	22 b	16
C3	——	25 a	24 a	16
M	——	23 b	22 b	16
IF	——	26 a	22 b	15
		*	*	NS
2003				
	g kg⁻¹			
C1	21	26	25	23
C2	21	27	25	23
C3	22	28	24	24
M	23	27	26	23
IF	25	28	25	23
	NS	NS	NS	NS

†Abbreviations: C1, compost 14 Mg $ha^{-1;}$ C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 23. Effects of composted dairy manure (29 Mg ha^{-1}) with four rates of supplemental N compared to inorganic fertilizer alone on tissue N concentrations in Coastal bermudagrass.

Treatment†	N rate	H1	H2	H3	H4
		2002			
	kg ha^{-1}	*g kg^{-1}*			
C2	0	——	19 c‡	18	12 c
C2	56	——	22 bc	20	14 b
C2	84	——	23 ab	21	15 ab
C2	112	——	24 ab	22	16 a
IF		——	26 a	22	15 ab
			*	NS	**
		2003			
		g kg^{-1}			
C2	0	15 c	14 d	15 d	14 c
C2	56	18 bc	22 c	20 c	20 b
C2	84	20 b	25 bc	22 b	21 ab
C2	112	21 b	27 ab	25 a	23 a
IF		25 a	28 a	25 a	23 a
		*	***	***	***

†Abbreviations: C2, compost 29 Mg ha^{-1}; N, (0, 56, 84 and 112 kg N ha^{-1} $cutting^{-1}$); IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 24. Effects of composted dairy manure (57 Mg ha^{-1}) with four rates of supplemental N compared to inorganic fertilizer alone on tissue N concentrations in Coastal bermudagrass.

Treatment†	N rate	2002 H1	2002 H2	2002 H3	2002 H4
	kg ha^{-1}	*g kg^{-1}*			
C3	0	——	18 c‡	17 c	12 b
C3	56	——	21 b	20 bc	15 a
C3	84	——	22 b	21 ab	16 a
C3	112	——	25 a	22 ab	16 a
IF		——	26 a	24 a	15 a
			***	*	***

Treatment†	N rate	2003 H1	2003 H2	2003 H3	2003 H4
		g kg^{-1}			
C3	0	15 b	15 c	15 d	14 c
C3	56	16 b	20 b	19 c	19 b
C3	84	21 a	25 a	22 b	20 b
C3	112	22 a	28 a	24 ab	24 a
IF		25 a	28 a	25 a	23 a
		**	***	***	***

†Abbreviations: C3, compost 57 Mg ha^{-1}; N, (0, 56, 84 and 112 kg N ha^{-1} $cutting^{-1}$); IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \le 0.05$, $P \le 0.01$ and $P \le 0.001$; NS = not significant; (Fishers Protected LSD).

Table 25. Effects of raw dairy manure (54 Mg ha^{-1}) with four rates of supplemental N compared to inorganic fertilizer alone on tissue N concentrations in Coastal bermudagrass.

Treatment†	N rate	H1	H2	H3	H4
		2002			
	kg ha^{-1}	*g kg^{-1}*			
M	0	——	18 c‡	18	12
M	56	——	23 b	22	14
M	84	——	24 ab	23	15
M	112	——	23 b	22	16
IF		——	26 a	22	15
			***	NS	NS
		2003			
		g kg^{-1}			
M	0	15 d	15 b	15 c	15 c
M	56	18 c	26 a	20 b	20 b
M	84	22 b	26 a	24 a	22 ab
M	112	23 ab	27 a	26 a	23 a
IF		25 a	28 a	25 a	23 a
		***	***	***	***

†Abbreviations: M, dairy manure 54 Mg ha^{-1}; N, (0, 56, 84 and 112 kg N ha^{-1} $cutting^{-1}$); IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Although yields in plots receiving compost or manure with supplemental N were equal to or greater than those receiving IF alone (Tables 10-12), these data suggest that inorganic fertilizer N was more readily available than compost and manure N pools. McIntosh and Varney (1972) found similar results showing increasing manure rate did not increase N concentration in corn ear leaves. In contrast, Schlegel (1992) reported that leaf N for grain sorghum increased linearly with increased rates of compost.

Apparent N recovery from compost, manure and IF treatments is presented in Table 26. Total apparent N recovery from compost and manure ranged from 23 to 57% compared to 70% for IF. Annual recovery rates were similar within most compost and manure treatments. Supplemental N did not consistently improve annual or total N recovery rates. Motavalli et al. (1989) reported apparent N recoveries of 19, 19 and 15% for dairy manure rates of 53, 97 and 138 Mg ha^{-1} yr^{-1} (wet basis), respectively, and Sullivan et al. (1997) reported cumulative annual apparent N recoveries in harvested prairiegrass receiving dairy manure of 17, 28 and 36%. Sanderson and Jones (1997) reported only 25% of dairy manure N was recovered in harvested forage over a 4 yr period. In this study, total N uptake in forage from compost and manure ranged from 57 to 214 kg N ha^{-1} compared to 627 kg N ha^{-1} for IF.

Application of compost or manure without supplemental fertilizer significantly increased tissue K concentrations compared to the untreated check (UC) in the first three harvests of 2002, with the exception of C2 at harvest 2 (Table 27). A similar response was observed in 2003. Tissue K concentrations in plots receiving C2, C3 and M were not different at harvests 2-4 in 2002 or for all four harvests in 2003. However, IF produced

Table 26. Apparent N recovery from dairy manure compost and raw dairy manure treatments with four rates of supplemental inorganic N compared to inorganic fertilizer.

		Compost/Manure			
Treatment†	Supplemental Inorganic	2002	2003	Total	Total N Uptake in Forage
	kg N ha^{-1} $cutting^{-1}$	— % Recovery —			kg ha^{-1}
C2 (250 kg N ha^{-1})	0	26	22	48	121
	56	25	32	57	142
	84	29	19	48	119
	112	17	6	23	57
C3 (500 kg N ha^{-1})	0	20	14	34	170
	56	19	15	34	168
	84	19	18	37	185
	112	19	10	29	146
M (420 kg N ha^{-1})	0	18	22	40	170
	56	25	25	50	211
	84	27	24	51	214
	112	13	11	24	98
	Inorganic N				
IF	112	55	83	70	627

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1});

Table 27. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue K concentrations in Coastal bermudagrass.

Treatment†	H1	H2	H3	H4
	2002			
	g kg^{-1}			
C2	22 b‡	17 bc	16 a	12
C3	25 a	19 ab	18 a	13
M	22 b	18 ab	14 a	12
IF	25 a	21 a	16 a	12
UC	16 c	14 c	13 b	9
	***	**	*	NS
	2003			
	g kg^{-1}			
C2	15 b	13 bc	11 bc	11 bc
C3	16 b	15 b	13 b	13 ab
M	16 b	14 b	14 b	12 abc
IF	22 a	19 a	18 a	14 a
UC	13 c	12 c	9 c	10 bc
	***	***	**	*

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** P $\leq$ 0.05, P $\leq$ 0.01 and P $\leq$ 0.001; NS = not significant; (Fishers Protected LSD).

greater tissue K concentrations than treatments C2, C3 and M in harvests 1-3 in 2003, suggesting that a majority of the available K in compost and manure was utilized in year 1. McIntosh and Varney (1972) reported increases in K concentrations in corn ear leaves with increasing manure rates (20, 41 and 60 Mg ha^{-1}).

Supplemental inorganic K (112 kg K_2O ha^{-1} $cutting^{-1}$) applied to plots receiving 29 Mg ha^{-1} of compost (C2) with 112 kg ha^{-1} $cutting^{-1}$ supplemental N did not increase tissue K concentrations compared to compost alone or IF in 2002 (Table 28). In contrast, C2 with supplemental K and IF had greater tissue K concentrations than C2 without supplemental K for the first three harvests of 2003, and a similar trend was observed in the fourth harvest. Nevertheless, only the third harvest in 2003 produced greater yields that could be attributed to supplemental K (Table 13).

When the compost rate was increased to 57 Mg ha^{-1}, supplemental K increased tissue K concentrations only at the third harvest of 2003 (Table 29). Compost with supplemental K also produced significantly greater tissue K concentrations than IF at harvests 1 and 3 in 2002; however, there were no differences in forage yields among these treatments in either year that could be attributed to a K response (Table 14).

When applied to raw manure plots receiving 112 kg ha^{-1} $cutting^{-1}$ of supplemental N, supplemental K (112 kg K_2O ha^{-1} $cutting^{-1}$) significantly increased tissue K concentrations at harvest 3 of 2002 and the first three harvests of 2003 (Table 30). However, tissue K concentrations in plots receiving manure with supplemental K were greater than IF only in harvest 3 of 2002. Cumulative forage yields for manure

Table 28. Effects of two rates of supplemental K applied to composted dairy manure (29 Mg ha^{-1}) receiving 112 kg ha^{-1} cutting^{-1} supplemental N compared to inorganic fertilizer alone on tissue K concentrations in Coastal bermudagrass.

Treatment†	K_20	H1	H2	H3	H4
		2002			
	kg ha $^{-1}$	*g kg $^{-1}$*			
C2	0	——	20‡	17	13
C2	112	——	22	19	15
IF		——	21	16	12
			NS	NS	NS
		2003			
		g kg $^{-1}$			
C2	0	14 b	12 b	9 b	10
C2	112	19 a	18 a	18 a	14
IF		22 a	19 a	18 a	14
		**	*	*	NS

†Abbreviations: C2, compost 29 Mg ha^{-1} + 112 kg N ha^{-1} cutting^{-1}; K, 0 and 112 kg K_2O ha^{-1} cutting^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 29. Effects of two rates of supplemental K applied to composted dairy manure (57 Mg ha^{-1}) receiving 112 kg ha^{-1} cutting^{-1} supplemental N compared to inorganic fertlizer alone on tissue K concentrations in Coastal bermudagrass.

		2002			
Treatment†	K_20	H1	H2	H3	H4
	kg ha $^{-1}$	*g kg $^{-1}$*			
C3	0	——	22 ab‡	20	14 ab
C3	112	——	23 a	20	16 a
IF		——	21 b	16	12 b
			*	NS	*
		2003			
		g kg $^{-1}$			
C3	0	19	15	11 b	12
C3	112	21	21	19 a	16
IF		22	19	18 a	14
		NS	NS	*	NS

†Abbreviations: C3, compost 57 Mg ha^{-1} + 112 kg N ha^{-1} cutting^{-1}; K, 0 and 112 kg K_2O ha^{-1} cutting^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 30. Effects of two rates of supplemental K applied to raw dairy manure ($54\ Mg\ ha^{-1}$) receiving $112\ kg\ ha^{-1}\ cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on tissue K concentrations in Coastal bermudagrass.

Treatment†	K_2O	H1	H2	H3	H4
		2002			
	kg ha^{-1}	*g kg^{-1}*			
M	0	——	21‡	18 b	14
M	112	——	22	21 a	14
IF		——	21	16 b	12
			NS	**	NS
		2003			
		g kg^{-1}			
M	0	15 b	13 b	8 b	12
M	112	21 a	20 a	20 a	15
IF		22 a	19 a	18 a	14
		*	**	**	NS

†Abbreviations: M, manure $54\ Mg\ ha^{-1} + 112\ kg\ N\ ha^{-1}\ cutting^{-1}$; K, 0 and $112\ kg\ K_2O\ ha^{-1}\ cutting^{-1}$; IF, inorganic fertilizer ($112\ kg\ N\ ha^{-1}$; $112\ kg\ P_2O_5\ ha^{-1}\ yr^{-1}$; $112\ kg\ K_2O\ ha^{-1}$).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

plots receiving supplemental K were significantly greater than manure alone and IF in 2002, and for the second harvest of 2003 (Table 15).

Total apparent K recovery from compost and manure ranged from 15 to 57 % and tended to increase with increasing supplemental inorganic N application up to 84 kg N ha^{-1} $cutting^{-1}$ (Table 31). Motavalli et al. (1989) reported apparent K recoveries of 23, 16 and 11% from dairy manure rates of 53, 97 and 138 Mg ha^{-1} yr^{-1} (wet basis). However, when supplemental inorganic K was applied to compost or manure plots with 112 kg N ha^{-1} $cutting^{-1}$ total apparent K recovery was similar to compost or manure without inorganic N. Total K uptake in forage from compost and manure ranged from 127 to 502 kg K ha^{-1} compared to 476 kg K ha^{-1} for IF. Treatment C3 with 112 kg N ha^{-1} $cutting^{-1}$ removed 100 kg K ha^{-1} or more than C2 or M with the same inorganic N rate. These differences in total K uptake support the yield and tissue data presented earlier, which indicated significant responses to supplemental inorganic K when applied to treatments C2 and M.

Tissue P concentrations in plots receiving C2, C3 and M without supplemental fertilizer were similar but significantly lower than those for IF in the first harvest of 2002 and the first two harvests of 2003 (Table 32). In contrast, C2, C3 and M had significantly greater P concentrations than IF in harvests 3 and 4 of 2002 and harvest 3 of 2003. Schlegel (1992) reported compost applications increased leaf P concentrations in grain sorghum and even at the lowest compost rate (2 Mg ha^{-1}) leaf P concentration was sufficient (above 3 g kg^{-1}).

Table 31. Apparent K recovery from dairy manure compost and raw dairy manure treatments with two rates of supplemental inorganic K compared to inorganic fertilizer.

	Supplemental Inorganic		Compost/Manure			
Treatment†	N	K	2002	2003	Total	Total K Uptake in Forage
	kg ha^{-1}	kg ha^{-1} cutting^{-1}	—— % Recovery ——			kg K ha^{-1}
C2 (665 kg K ha^{-1})	0	0	11	9	20	132
	56	0	24	15	39	262
	84	0	31	26	57	378
	112	0	27	22	49	329
	112	93	14	6	20	127
C3 (1310 kg K ha^{-1})	0	0	11	6	17	224
	56	0	17	15	32	426
	84	0	18	20	38	502
	112	0	19	18	37	484
	112	93	9	6	15	193
M (753 kg K ha^{-1})	0	0	14	14	28	210
	56	0	29	22	51	383
	84	0	30	22	52	390
	112	0	27	23	50	381
	112	93	15	10	25	185
	—— Inorganic K ——					
IF	112	93	56	71	64	476

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1});

Table 32. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue P concentrations in Coastal bermudagrass.

Treatment†	H1	H2	H3	H4
	2002			
	g kg⁻¹			
C2	3.3 bc‡	2.4	2.5 a	1.7 ab
C3	3.5 b	2.7	2.8 a	1.9 a
M	3.1 c	2.6	2.7 a	1.7 ab
IF	4.0 a	2.7	2.2 b	1.3 c
UC	2.4 d	2.1	2.0 b	1.4 bc
	***	NS	***	**
	2003			
	g kg⁻¹			
C2	2.9 c	3.0 c	2.8 b	2.2
C3	3.3 b	3.4 b	3.1 a	2.5
M	3.0 bc	3.0 c	2.9 ab	2.4
IF	4.0 a	3.8 a	2.1 c	2.1
UC	2.1 d	1.8 d	1.8 c	1.8
	***	***	***	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Inorganic P (112 kg P_2O_5 ha^{-1} yr^{-1}) was applied as a single application in the spring of both years to compost and raw dairy manure treatments receiving 112 kg N ha^{-1} $cutting^{-1}$. Phosphorus concentrations in tissue were not significantly different in plots receiving compost (C2 and C3) or raw dairy manure (M) with or without supplemental P in 2002 (Table 33-35). However, C2, C3 and M treatments with and without supplemental P had significantly greater tissue P concentrations than IF in the third harvest of 2002, and the C3 treatment also was significantly greater than IF in the fourth harvest. In 2003, C2 with supplemental P had greater tissue P concentrations than C2 alone in harvests 1-3, and a similar result was observed for C3 at harvest 1 and M at harvests 1 and 2. In addition, C2, C3 and M with supplemental P had greater tissue P concentrations than IF at harvest 3 in 2003, and a similar trend was observed for harvest 4.

Total apparent P recovery from compost and manure ranged from 13 to 60% and tended to increase with increasing supplemental inorganic N application up to 84 kg N ha^{-1} $cutting^{-1}$ (Table 36). Sanderson and Jones (1997) reported apparent P recovery from dairy manure in harvested forage during 4 yr was 20% or less and Motavalli et al. (1989) reported apparent P recoveries of 13, 12 and 16% from dairy manure rates of 53, 97 and 138 Mg ha^{-1} yr^{-1} (wet basis). However, when supplemental inorganic P was applied to C3 and M with 112 kg N ha^{-1} $cutting^{-1}$ total apparent P recovery was lower than their respective treatments without supplemental inorganic N. In contrast, when supplemental P was applied to C2 with the same N rate the apparent recovery increased compared to

Table 33. Effects of two rates of supplemental P applied to composted dairy manure (29 Mg ha^{-1}) receiving 112 kg ha^{-1} $cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on tissue P concentrations in Coastal bermudagrass.

Treatment†	P_2O_5	H1	H2	H3	H4
		2002			
	kg ha $^{-1}$	*g kg* $^{-1}$			
C2	0	——	2.8‡	2.5 a	1.7
C2	112	——	3.0	2.8 a	1.7
IF		——	2.7	2.1 b	1.3
			NS	**	NS
		2003			
		g kg $^{-1}$			
C2	0	2.6 b	2.9 b	2.6 b	2.3
C2	112	3.3 a	3.5 a	2.9 a	2.5
IF		4.0 a	3.8 a	2.1 c	2.1
		*	*	**	NS

†Abbreviations: C2, compost 29 Mg ha^{-1} + 112 kg N ha^{-1} $cutting^{-1}$; P, 0 and 112 kg P_2O_5 ha^{-1} yr^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 34. Effects of two rates of supplemental P applied to composted dairy manure (57 Mg ha^{-1}) receiving 112 kg ha^{-1} $cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on tissue P concentrations in Coastal bermudagrass.

Treatment†	P_2O_5	H1	H2	H3	H4
		2002			
	kg ha $^{-1}$	*g kg* $^{-1}$			
C3	0	——	2.8‡	2.9 a	1.7 a
C3	112	——	2.9	2.8 a	1.7 a
IF		——	2.7	2.2 b	1.3 b
			NS	*	**
		2003			
		g kg $^{-1}$			
C3	0	2.9 c	3.3	2.4 ab	2.4
C3	112	3.4 b	3.8	2.9 a	2.4
IF		4.0 a	3.8	2.1 b	2.1
		**	NS	*	NS

†Abbreviations: C3, compost 57 Mg ha^{-1} + 112 kg N ha^{-1} $cutting^{-1}$; P, 0 and 112 kg P_2O_5 ha^{-1} yr^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 35. Effects of two rates of supplemental P applied to raw dairy manure (54 Mg ha^{-1}) receiving 112 kg ha^{-1} $cutting^{-1}$ supplemental N compared to inorganic fertilizer alone on tissue P concentrations in Coastal bermudagrass.

Treatment†	P_2O_5	H1	H2	H3	H4
		2002			
	kg ha $^{-1}$	*g kg* $^{-1}$			
M	0	——	2.5‡	2.5 a	1.7
M	112	——	2.8	2.6 a	1.7
IF		——	2.7	2.2 b	1.3
			NS	*	NS
		2003			
		g kg $^{-1}$			
M	0	2.6 b	3.0 b	2.7 a	2.3
M	112	3.7 a	3.9 a	2.9 a	2.3
IF		4.0 a	3.8 a	2.1 b	2.1
		**	**	**	NS

†Abbreviations: M, manure 54 Mg ha^{-1} + 112 kg N ha^{-1} $cutting^{-1}$; P, 0 and 112 kg P_2O_5 ha^{-1} yr^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}).

‡Means within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 36. Apparent P recovery from dairy manure compost and raw dairy manure treatments with two rates of supplemental inorganic P compared to inorganic fertilizer.

	Supplemental Inorganic		Compost/Manure			
Treatment†	N	P	2002	2003	Total	Total P Uptake in Forage
	kg ha^{-1}	kg ha^{-1} yr^{-1}	—— % Recovery ——			kg P ha^{-1}
C2 (118 kg P ha^{-1})	0	0	10	13	23	27
	56	0	20	27	47	56
	84	0	22	32	54	64
	112	0	21	32	53	63
	112	49	16	17	33	39
C3 (225 kg P ha^{-1})	0	0	9	9	18	41
	56	0	13	17	30	68
	84	0	13	20	33	74
	112	0	14	20	34	77
	112	49	8	5	13	30
M (113 kg P ha^{-1})	0	0	13	20	33	38
	56	0	22	33	55	63
	84	0	24	36	60	69
	112	0	22	36	58	66
	112	49	11	8	19	22
	—— Inorganic P ——					
IF	112	49	52	90	71	70

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1});

C2 without supplemental N. Total P uptake in forage ranged from 22 to 77 kg P ha^{-1} for compost and manure treatments compared to 70 kg P ha^{-1} for IF.

Plant tissue calcium (Ca) concentrations were significantly greater for the C2, C3 and M treatments compared to IF in 2003 but were not different from UC (Table 37). Sulfur (S) concentrations in plant tissue were significantly greater in compost (C2 and C3) and manure (M) plots compared to IF in both years, but were similar to UC (Table 38). Lower yields in the UC treatment and the addition of S in compost and manure treatments were likely responsible for observed differences.

Manganese (Mn) concentrations in plant tissue were lower in the compost (C2 and C3) and manure treatments compared to IF or UC in 2003 (Table 39). This likely was due to the liming effect of those treatments and the resulting increase in soil pH. Zinc (Zn) concentrations in plant tissue were significant but only slightly greater in the C3 and M treatments compared to IF, most likely due to the greater amounts supplied by the higher rates of organic material application (Table 40).

There were no significant differences among compost (C2 and C3) and raw dairy manure (M) without supplemental fertilizer, inorganic fertilizer (IF) and the untreated check (UC) for tissue concentrations of boron (B), copper (Cu), iron (Fe), magnesium (Mg), sodium (Na) or acid-detergent fiber (ADF) in either year (Tables 41-46).

Table 37. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue Ca concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	mg kg^{-1}	
C2	4,911‡	4,164 a
C3	4,713	4,039 a
M	4,178	4,065 a
IF	4,247	3,437 b
UC	4,985	4,101 a
	NS	***

Table 38. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue S concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	mg kg^{-1}	
C2	4,414 ab‡	4,066 a
C3	4,721 a	4,052 a
M	4,056 b	3,925 a
IF	3,331 c	3,429 b
UC	3,954 b	3,748 ab
	***	*

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means (averaged across all harvests within a year) within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 39. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue Mn concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	mg kg $^{-1}$	
C2	134‡	97 c
C3	131	84 c
M	139	88 c
IF	141	122 b
UC	156	141 a
	NS	***

Table 40. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue Zn concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	mg kg $^{-1}$	
C2	26‡	24 ab
C3	26	25 a
M	27	26 a
IF	25	21 b
UC	26	24 ab
	NS	*

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means (averaged across all harvests within a year) within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 41. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue B concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	g kg $^{-1}$	
C2	10‡	7
C3	14	8
M	11	9
IF	9	6
UC	12	7
	NS	NS

Table 42. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue Cu concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	mg kg $^{-1}$	
C2	13‡	12
C3	13	12
M	13	12
IF	12	11
UC	13	12
	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means (averaged across all harvests within a year) within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 43. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue Fe concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	mg kg^{-1}	
C2	139‡	150
C3	157	153
M	140	173
IF	135	160
UC	187	185
	NS	NS

Table 44. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue Mg concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	mg kg^{-1}	
C2	2,256‡	1,931
C3	1,918	1,680
M	1,825	1,843
IF	2,353	2,000
UC	2,225	1,765
	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means (averaged across all harvests within a year) within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 45. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on tissue Na concentrations in Coastal bermudagrass.

Treatment†	2002	2003
	mg kg⁻¹	
C2	2,167‡	1,861
C3	2,056	1,723
M	2,047	1,916
IF	2,066	1,874
UC	2,383	1,790
	NS	NS

Table 46. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on Coastal bermudagrass ADF.

Treatment†	2002	2003
	g kg⁻¹	
C2	360‡	340
C3	350	340
M	350	340
IF	360	340
UC	340	330
	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means (averaged across all harvests within a year) within a year and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Soil Chemical Properties

The 29 and 57 Mg ha^{-1} rates of compost and the single rate of raw dairy manure without supplemental fertilizer were compared to inorganic fertilizer alone and the untreated check to evaluate treatment effects on soil chemical properties. There were year by treatment interactions for pH, OC, all measured soil nutrients, Na and EC. Individual values represent the mean of composite samples from three replications. Summary of soil chemical properties for all treatments are provided in Appendix A to O.

Dairy manure compost and raw manure significantly increased soil pH in the 0 to 5-cm zone compared to IF and UC for both sampling dates (Table 47). However, there were no treatment differences observed with depth. The liming effect was attributed largely to the inclusion of calcareous soil material as part of the compost and manure treatments. Eghball (1999) reported an increase in soil surface (0 to 15-cm) pH in plots receiving feedlot manure or compost. The pH increase was attributed to the beef cattle diet which contained approximately 15 g $CaCO_3$ kg^{-1}. Sanderson and Jones (1997) reported soil pH increased in the surface 15 cm with increasing manure rate and with each year of the experiment.

Application of composted dairy manure or raw manure did not increase soil OC levels in this study (Table 48). This was due primarily to the low OC concentrations in these organic materials. Manure obtained from open lot dairies contains significant amounts of mineral material that is picked up during the collection process. Composting further reduces the OC concentration. In addition, warm temperatures and above average moisture conditions in 2002 likely promoted further microbial decomposition of the

Table 47. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil pH on two sampling dates.

	February-03		
Treatment†	0-5 cm	5-15 cm	15-30 cm
C2	6.4 b‡	5.2	6.6
C3	6.9 a	5.7	6.6
M	6.5 b	5.4	6.6
IF	4.6 c	5.3	6.7
UC	4.8 c	5.3	6.5
	***	NS	NS
	November-03		
	0-5 cm	5-15 cm	15-30 cm
C2	6.5 b	4.9	6.6
C3	7.1 a	5.6	6.6
M	6.6 b	5.5	6.5
IF	4.3 c	4.8	6.4
UC	4.5 c	5.0	6.5
	***	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 48. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil OC concentrations following the first and second growing season.

	February-03	
Treatment†	0-5 cm	5-15 cm
	——— *g kg*$^{-1}$ ———	
C2	27‡	5
C3	29	5
M	31	5
IF	32	5
UC	29	5
	NS	NS

	November-03	
	0-5 cm	5-15 cm
	——— *g kg*$^{-1}$ ———	
C2	30	6
C3	32	8
M	30	7
IF	32	5
UC	31	6
	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** P $\leq$ 0.05, P $\leq$ 0.01 and P $\leq$ 0.001; NS = not significant; (Fishers Protected LSD).

residue and consequential OC loss. Organic carbon concentrations of compost and manure used in this study averaged 84 and 93 g kg^{-1}, respectively (Table 2). In contrast, Schlegel (1992) reported linear increases in soil organic matter with increasing compost rate and Sommefeldt et al. (1988) reported linear increases in soil organic matter with manure rates up to 29 Mg ha^{-1}.

Soil NH_4 concentrations in the 0 to 5-cm zone were greater for M compared to IF and UC in February 2003, and a similar trend was observed for C2 and C3 (Table 49). Ammonium concentrations in the 0 to 5-cm zone ranged from 149 to 346 mg kg^{-1}. However, there were no differences among treatments in the 5 to 15-cm depth at that time, or for either depth in November 2003. Chang et al. (1991) reported that despite high NH_4 concentrations in manure, repeated annual applications of the manure did not affect soil NH_4 levels.

Soil NO_3 concentrations in the 0 to 5-cm zone were greater in the C2, C3 and M treatments compared to IF and UC in February 2003 (Table 50). The highest concentration (165 mg kg^{-1}) was observed in the C3 (57 Mg ha^{-1}) treatment. However, there were no differences among treatments for soil NO_3 in the 5 to 15- or 15 to 30-cm depths. By November 2003, soil NO_3 concentrations were substantially lower, but remained significantly greater at 0 to 5 cm for the M treatment compared to other treatments. Soil NO_3 values in November were very low, ranging from 2 to 5 mg kg^{-1}. There was no evidence of downward migration or accumulation of NO_3 in the profile at depths of 5 to 15 and 15 to 30 cm on either sampling date. Schlegel (1992) reported annual application of beef cattle compost up to 16 Mg ha^{-1} had no effect

Table 49. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil NH_4 concentrations following the first and second growing season.

	February-03	
Treatment†	0-5 cm	5-15 cm
	mg kg $^{-1}$	
C2	270 abc‡	14
C3	291 ab	21
M	346 a	18
IF	212 bc	16
UC	149 c	17
	*	NS

	November-03	
	0-5 cm	5-15 cm
	mg kg $^{-1}$	
C2	101	12
C3	97	11
M	90	11
IF	71	9
UC	42	7
	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 50. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil NO_3 concentrations following the first and second growing season.

	February-03		
Treatment†	0-5 cm	5-15 cm	15-30 cm
	mg kg^{-1}		
C2	86 b‡	3	2
C3	165 a	4	5
M	98 ab	3	2
IF	2 c	4	3
UC	4 c	3	3
	**	NS	NS

	November-03		
	0-5 cm	5-15 cm	15-30 cm
	mg kg^{-1}		
C2	4 b	3	4
C3	4 b	3	3
M	5 a	3	2
IF	2 c	3	3
UC	4 b	2	2
	***	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

on soil NO_3 after 2 and 4 yr. Xie and MacKenzie (1986) reported similar results, showing no residual effects on soil NO_3 from 2 yr of compost applications when samples were collected the following spring. Sanderson and Jones (1997) reported soil NO_3 increased with increasing manure rate, but NO_3 concentrations below 15 cm were not affected by manure treatment. They also reported that although NO_3 levels in the soil increased, a maximum of only 7 mg kg^{-1} accumulated in the surface 15 cm.

Soil P concentrations in the 0 to 5-cm zone were significantly greater in the C2, C3 and M treatments compared to IF and UC in February 2003 (Table 51). A similar result was observed for C2 and C3 in November 2003. However, only the C3 treatment resulted in soil P concentrations greater than 200 mg kg^{-1}, averaging 217 and 231 mg kg^{-1} in February and November 2003, respectively. Application of 112 kg P_2O_5 ha^{-1} as inorganic fertilizer (IF) increased the soil P concentration in the 0 to 5-cm zone only slightly compared to UC. There were no differences among treatments in the 5 to 15- or 15 to 30-cm zones for either sampling date. A long-term study conducted by Ferguson and Nienaber (2000) reported soil P levels in the top 0.6 m increased significantly with beef feedlot manure or compost application, but no evidence of P movement below that depth was observed. Chang et al. (1991) observed similar results after 11 annual applications of feedlot manure under irrigated conditions, and under non-irrigated conditions the effects of manure application on total P in the soil were restricted to the upper 30-cm zone.

Application of compost at 57 Mg ha^{-1} (C3) significantly increased soil K concentrations in the 0 to 5- and 5 to 15-cm zones compared to other treatments in

Table 51. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil P concentrations following the first and second growing season.

	February-03		
Treatment†	0-5 cm	5-15 cm	15-30 cm
	mg kg⁻¹		
C2	106 b‡	3	2
C3	217 a	5	2
M	108 b	6	5
IF	25 c	3	1
UC	22 c	3	2
	***	NS	NS

	November-03		
	0-5 cm	5-15 cm	15-30 cm
	mg kg⁻¹		
C2	86 b	7	2
C3	231 a	17	3
M	63 bc	12	3
IF	31 c	7	2
UC	22 c	6	3
	***	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

February 2003 (Table 52). Soil K values for C2, M and IF were not different from each other at any depth, but were greater than UC in the 0 to 5-cm zone. The C3 treatment maintained higher soil K concentrations compared to other treatments in the 0 to 5- and 5 to 15-cm zones in November with the exception of IF in the 0 to 5-cm zone. Schlegel (1992) reported soil K increased linearly with increasing cattle manure compost rates. In this study, the 57 Mg ha^{-1} compost rate supplied 1170 kg K ha^{-1} compared to 594 and 672 kg K ha^{-1} from C2 and M, respectively. These results correlate with the yield response to supplemental K observed for treatments C2 and M in 2002 and 2003 (Tables 13 & 15).

Application of compost or manure significantly increased soil Ca concentrations in the 0 to 5-cm zone for both sampling dates compared to IF and UC (Table 53). Increasing compost application rate also affected soil Ca levels in the surface zone, but there were no differences among treatments in the 5 to 15- or 15 to 30-cm zones on either sampling date. Soil series common to this region such as Bolar, Blanket, Dugout and Frio contain significant amounts of free carbonates, which are inadvertently collected along with manure during the lot cleanout process (USDA, 1973).

Application of compost or manure significantly increased soil Mg concentrations in the 0 to 5-cm zone for both sampling dates compared to IF and UC (Table 54). Increasing compost rate also affected soil Mg levels in the surface zone and in the 5 to 15-cm depth in November. Likewise, compost and manure treatments increased soil S concentrations in the 0 to 5-cm zone in February, but there were no differences among

Table 52. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil K concentrations following the first and second growing season.

	February-03		
Treatment†	0-5 cm	5-15 cm	15-30 cm
	mg kg $^{-1}$		
C2	232 b‡	91 b	142
C3	379 a	174 a	159
M	261 b	104 b	142
IF	245 b	105 b	141
UC	146 c	66 b	177
	***	*	NS

	November-03		
	0-5 cm	5-15 cm	15-30 cm
	mg kg $^{-1}$		
C2	145 b	86 b	152
C3	252 a	173 a	185
M	149 b	88 b	168
IF	215 a	116 b	140
UC	122 b	88 b	190
	**	**	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 53. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil Ca concentrations following the first and second growing season.

	February-03		
Treatment†	0-5 cm	5-15 cm	15-30 cm
	mg kg⁻¹		
C2	2,362 b‡	645	1,972
C3	5,344 a	643	1,825
M	2,250 b	692	2,010
IF	557 c	586	1,967
UC	635 c	646	2,105
	***	NS	NS

	November-03		
	0-5 cm	5-15 cm	15-30 cm
	mg kg⁻¹		
C2	2,676 b	592	1,919
C3	5,836 a	792	1,813
M	2,045 b	675	1,891
IF	373 c	412	1,666
UC	679 c	676	2,180
	***	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 54. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil Mg concentrations following the first and second growing season.

		February-03	
Treatment†	0-5 cm	5-15 cm	15-30 cm
		mg kg $^{-1}$	
C2	252 b‡	83	261
C3	388 a	77	209
M	297 b	85	278
IF	66 c	82	334
UC	106 c	76	223
	***	NS	NS

		November-03	
	0-5 cm	5-15 cm	15-30 cm
		mg kg $^{-1}$	
C2	211 b	92 b	226
C3	357 a	109 a	198
M	213 b	94 b	254
IF	52 d	68 c	254
UC	113 c	87 b	195
	***	***	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

the treatments below this depth in February or for any depth in November 2003 (Table 55).

There were no differences in soil Cu concentrations among soil depths with the exception of the 0 to 5-cm depth in February (Table 56). Plots receiving raw dairy manure (M) had significantly greater soil Cu concentrations than the other four treatments, which were not different. There was no clear explanation for this result since the raw manure had a lower concentration than the compost used in this study. Chang et al. (1991) reported the Cu concentration in the soil for their study was very low and was not changed by the application of manure.

The UC and IF treatments had greater soil Fe concentrations than either compost rate (C2 and C3) or the raw manure (M) in the 0 to 5-cm zone at both sampling dates (Table 57). This difference is attributable to the low pH observed in the 0 to 5-cm zone in UC and IF plots (Table 47), and the liming affect of the manure and compost treatments. No differences in Fe concentrations were observed among any of the treatments in the 5 to 15-cm zone on either date.

Soil Mg concentrations were greater in the M treatment compared to compost or IF, but not UC in February 2003 (Table 58). The differences were no longer present in November 2003, and treatment effects observed in the 5 to 15-cm zone at that time were attributed to soil variability.

There were no differences among treatments for soil Zn at either depth in February 2003, while differences observed in the 0 to 5-cm zone in November 2003 were not considered to be biologically significant (Table 59).

Table 55. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil S concentrations following the first and second growing season.

	February-03		
Treatment†	0-5 cm	5-15 cm	15-30 cm
	mg kg $^{-1}$		
C2	94 b‡	27	30
C3	152 a	26	28
M	127 a	28	28
IF	57 c	26	26
UC	52 c	20	27
	***	NS	NS

	November-03		
	0-5 cm	5-15 cm	15-30 cm
	mg kg $^{-1}$		
C2	49	23	21
C3	57	28	19
M	43	23	17
IF	41	25	19
UC	42	25	20
	NS	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 56. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil Cu concentrations following the first and second growing seasons.

	February-03	
Treatment†	0-5 cm	5-15 cm
	mg kg⁻¹	
C2	0.22 b‡	0.28
C3	0.22 b	0.26
M	0.35 a	0.25
IF	0.24 b	0.26
UC	0.26 b	0.28
	*	NS

	November-03	
	0-5 cm	5-15 cm
	mg kg⁻¹	
C2	0.19	0.18
C3	0.26	0.24
M	0.26	0.24
IF	0.20	0.20
UC	0.27	0.25
	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 57. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil Fe concentrations following the first and second growing season.

	February-03	
Treatment†	0-5 cm	5-15 cm
	mg kg^{-1}	
C2	31 b‡	33
C3	23 b	27
M	31 b	30
IF	61 a	32
UC	63 a	25
	***	NS

	November-03	
	0-5 cm	5-15 cm
	mg kg^{-1}	
C2	50 b	49
C3	33 b	45
M	38 b	52
IF	73 a	51
UC	92 a	43
	***	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 58. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil Mn concentrations following the first and second growing season.

	February-03	
Treatment†	0-5 cm	5-15 cm
	mg kg $^{-1}$	
C2	11 bc‡	32
C3	10 bc	24
M	17 a	25
IF	8 c	33
UC	13 ab	32
	*	NS

	November-03	
	0-5 cm	5-15 cm
	mg kg $^{-1}$	
C2	12	36 a
C3	18	22 b
M	17	27 ab
IF	8	36 a
UC	14	36 a
	NS	**

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 59. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil Zn concentrations following the first and second growing season.

	February-03	
Treatment†	0-5 cm	5-15 cm
	mg kg⁻¹	
C2	3‡	0.17
C3	2	0.15
M	3	0.15
IF	2	0.14
UC	3	0.13
	NS	NS

	November-03	
	0-5 cm	5-15 cm
	mg kg⁻¹	
C2	2 c	0.24
C3	4 a	0.37
M	3 b	0.37
IF	2 c	0.24
UC	3 b	0.23
	**	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Soil Na concentrations were only slightly affected by the application of compost or manure (Table 60). Sodium concentrations were significantly greater in the 0 to 5-cm zone for the C3 treatment compared to C2, IF and UC. However, there were no differences among treatments for the 5 to 15- or 15 to 30-cm zones in February or for any depth in November 2003. Schlegel (1992) reported soil Na increased linearly with increasing rates of composted beef feedlot manure, but crop production was not adversely affected.

Soil EC in the 0 to 5-cm zone increased with the addition of compost and manure compared to IF and UC in February (Table 61). However, the increase was very modest with values ranging from 0.64 to 0.75 dS m^{-1}, and not sufficient to adversely affect plant growth. Conductivity values in the 5 to 15- and 15 to 30-cm zones were not affected by treatment. In addition, leaching and/or dilution of added salts resulted in no differences among treatments for any depth increment in November 2003. Chang et al. (1991) reported the EC of the soil increased in the 0 to 150-cm depth with increasing rates of manure under irrigated conditions and under non-irrigated conditions the increase was observed to a depth of 90 cm.

Table 60. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil Na concentrations following the first and second growing season.

	February-03		
Treatment†	0-5 cm	5-15 cm	15-30 cm
	mg kg^{-1}		
C2	330 d‡	372	410
C3	393 a	365	376
M	368 ab	362	389
IF	332 cd	344	388
UC	361 bc	337	340
	**	NS	NS

	November-03		
	0-5 cm	5-15 cm	15-30 cm
	mg kg^{-1}		
C2	318	272	272
C3	354	297	289
M	345	255	317
IF	314	271	275
UC	330	269	270
	NS	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

Table 61. Effects of dairy manure compost, raw dairy manure and inorganic fertilizer alone on soil electrical conductivity on two sampling dates.

	February-03		
Treatment†	0-5 cm	5-15 cm	15-30 cm
	dS m^{-1}		
C2	0.64 a‡	0.04	0.05
C3	0.68 a	0.05	0.07
M	0.75 a	0.05	0.05
IF	0.23 b	0.05	0.06
UC	0.17 b	0.03	0.06
	*	NS	NS

	November-03		
	0-5 cm	5-15 cm	15-30 cm
	dS m^{-1}		
C2	0.21	0.17	0.13
C3	0.25	0.17	0.15
M	0.18	0.09	0.17
IF	0.16	0.09	0.17
UC	0.19	0.13	0.16
	NS	NS	NS

†Abbreviations: C2, compost 29 Mg ha^{-1}; C3, compost 57 Mg ha^{-1}; M, manure 54 Mg ha^{-1}; IF, inorganic fertilizer (112 kg N ha^{-1}; 112 kg P_2O_5 ha^{-1} yr^{-1}; 112 kg K_2O ha^{-1}); UC, untreated check.

‡Means within a date and column followed by the same letter are not significantly different.

*,**,*** $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$; NS = not significant; (Fishers Protected LSD).

CHAPTER III

CONCLUSIONS

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 its ability to support rapidly growing, warm season crops. Forage yields produced by compost (29 and 57 Mg ha^{-1}) and raw dairy manure (54 Mg ha^{-1}) alone were significantly greater than the untreated check (UC), but less than IF in both years. Supplemental inorganic fertilizer rates as low as 56 kg N ha^{-1} $cutting^{-1}$ applied to compost and manure treatments produced yields that were undifferentiated from those obtained using inorganic fertilizer alone at the recommended rate (112 kg N ha^{-1} $cutting^{-1}$, 112 kg P_2O_5 ha^{-1} yr^{-1}, 112 kg K_2O ha^{-1} $cutting^{-1}$). Increasing supplemental N fertilizer rates to 84 or 112 kg N ha^{-1} $cutting^{-1}$ produced forage yields in compost and manure plots that were equal to or greater than those in IF, but may not be adequate to offset increased input costs.

Tissue N concentrations tended to increase with increasing rates of supplemental N applied to compost or manure. Although forage yields equivalent to inorganic fertilizer were obtained with 56 kg ha^{-1} $cutting^{-1}$ of supplemental N, tissue N concentrations in compost and manure treatments were lower than IF for the majority of harvests. When supplemental N rates were increased to 84 or 112 kg N ha^{-1} $cutting^{-1}$, tissue N concentrations generally were not different from IF. Total apparent N recovery from dairy manure compost and dairy manure ranged from 23 to 57% of the total amount applied compared to 70% from inorganic fertilizer alone. Overall, uptake of N derived from compost or manure did not appear to be as efficient as it was from plots receiving only inorganic fertilizer.

Dairy manure compost applied at 29 Mg ha^{-1} and raw dairy manure applied at 54 Mg ha^{-1} with 112 kg N ha^{-1} $cutting^{-1}$ produced significant yield and tissue K responses to applications of supplemental inorganic K. Apparent K recovery ranged from 15 to 57% and tended to increase with increasing supplemental N rate to 84 kg N ha^{-1} $cutting^{-1}$. Lower total K uptake in forage from C2 and M treatments compared to C3 suggests that application of compost and manure at these rates may require supplemental inorganic K by the end of the first growing season and for the majority of the second season.

There were no yield responses to supplemental inorganic P for C2, C3 and M with 112 kg N ha^{-1} $cutting^{-1}$ in either year. Application of supplemental P tended to increase tissue P concentrations compared to compost or manure alone, and to produce levels equal to or greater than IF. Greater responses to supplemental P were observed for the 29 Mg ha^{-1} rate of compost and 54 Mg ha^{-1} rate of manure. Total apparent P recovery ranged from 13 to 60% and tended to increase with increasing rate of supplemental N to 84 kg N ha^{-1} $cutting^{-1}$. In general P recovery from compost and manure appeared to be adequate to supply crop demands throughout both growing seasons.

Compost or manure alone did not significantly effect tissue concentrations of B, Cu, Fe, Mg, Na or ADF in either year compared to IF or UC. However, application of compost or manure tended to increase tissue concentrations of Ca, S and Zn compared to IF.

Application of composted dairy manure or raw dairy manure increased soil pH due to the inclusion of calcareous soil material collected during manure harvest from open lot dairies. Both compost and manure tended to increase soil NH_4 and NO_3 concentrations in the 0 to 5-cm zone compared to IF and UC; however, there was no evidence of downward migration or accumulation of NO_3 below the 0 to 5-cm zone after two growing seasons. Compost applied at 57 Mg ha^{-1} resulted in soil P concentrations that exceeded 200 mg kg^{-1} in the 0 to 5-cm depth on both sampling dates. Compost application rates should be adjusted based on soil testing to maintain soil P concentrations within appropriate state regulatory thresholds. Increases in soil K, Ca, Mg, S and Mn concentrations and soil EC were observed for C2, C3 and M in the 0 to 5-cm zone for the first sampling date when compared to UC and IF.

Dairy manure compost applied at rates of 29 or 57 Mg ha^{-1} was an effective nutrient source for production of Coastal bermudagrass. However, the application of supplemental inorganic N for each harvest and supplemental K for the lower compost rate will be necessary to produce yields and ensure nutritive values comparable to that achieved using inorganic fertilizer alone.

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APPENDIX A

February 2003 Soil pH

Treatment	Supplemental Inorganic Fertilizer N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}			
C1	56	0	0	5.6	5.0	6.6
C1	112	0	0	5.6	5.4	6.8
C2	0	0	0	6.4	5.2	6.6
C2	56	0	0	6.6	5.2	6.8
C2	84	0	0	6.6	5.5	6.6
C2	112	0	0	6.4	5.3	6.7
C2	112	0	112	6.3	5.4	6.6
C2	112	112	0	6.3	5.5	6.7
C3	0	0	0	6.9	5.7	6.6
C3	56	0	0	6.6	5.4	7.0
C3	84	0	0	6.6	5.4	6.8
C3	112	0	0	6.6	5.5	6.7
C3	112	0	112	6.5	5.4	6.9
C3	112	112	0	6.5	5.6	6.9
M	0	0	0	6.5	5.4	6.6
M	56	0	0	6.5	5.3	6.5
M	84	0	0	6.6	5.6	6.4
M	112	0	0	6.7	5.5	6.6
M	112	0	112	6.3	4.9	6.6
M	112	112	0	6.4	5.5	6.8
UC	0	0	0	4.8	5.3	6.6
IF	112	112	112	4.6	5.3	6.7

November 2003 Soil pH

Treatment	Supplemental Inorganic Fertilizer N	K$_2$O	P$_2$O$_5$	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}			
C1	56	0	0	6.6	5.3	6.7
C1	112	0	0	6.1	5.2	6.5
C2	0	0	0	6.5	4.9	6.6
C2	56	0	0	6.5	5.4	6.9
C2	84	0	0	6.4	5.2	6.6
C2	112	0	0	6.1	5.4	6.7
C2	112	0	112	5.9	5.2	6.6
C2	112	112	0	5.9	5.1	6.4
C3	0	0	0	7.1	5.6	6.6
C3	56	0	0	6.9	5.9	7.0
C3	84	0	0	6.9	5.7	6.6
C3	112	0	0	6.7	5.5	6.8
C3	112	0	112	6.7	5.5	6.6
C3	112	112	0	6.7	5.3	6.4
M	0	0	0	6.6	5.5	6.5
M	56	0	0	6.2	5.2	6.6
M	84	0	0	5.7	5.1	5.9
M	112	0	0	5.5	5.0	6.7
M	112	0	112	5.3	4.9	6.6
M	112	112	0	5.7	5.1	6.5
UC	0	0	0	4.5	5.0	6.5
IF	112	112	112	4.3	4.8	6.4

APPENDIX B

February 2003 Soil OC Concentrations

	Supplemental Inorganic Fertilizer				
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	g kg^{-1}	
C1	56	0	0	31	6
C1	112	0	0	34	5
C2	0	0	0	27	5
C2	56	0	0	23	6
C2	84	0	0	31	6
C2	112	0	0	27	6
C2	112	0	112	30	6
C2	112	112	0	30	5
C3	0	0	0	29	5
C3	56	0	0	32	6
C3	84	0	0	40	6
C3	112	0	0	33	7
C3	112	0	112	34	6
C3	112	112	0	32	6
M	0	0	0	31	5
M	56	0	0	32	7
M	84	0	0	28	5
M	112	0	0	28	5
M	112	0	112	35	7
M	112	112	0	27	6
UC	0	0	0	29	6
IF	112	112	112	32	5

November 2003 Soil OC Concentrations

	Supplemental Inorganic Fertilizer				
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	g kg^{-1}	
C1	56	0	0	26	6
C1	112	0	0	33	6
C2	0	0	0	30	6
C2	56	0	0	31	7
C2	84	0	0	32	6
C2	112	0	0	32	6
C2	112	0	112	35	6
C2	112	112	0	27	6
C3	0	0	0	32	8
C3	56	0	0	31	6
C3	84	0	0	36	7
C3	112	0	0	35	7
C3	112	0	112	36	6
C3	112	112	0	40	7
M	0	0	0	30	7
M	56	0	0	32	7
M	84	0	0	34	6
M	112	0	0	31	7
M	112	0	112	37	7
M	112	112	0	31	7
UC	0	0	0	31	6
IF	112	112	112	32	5

APPENDIX C

February 2003 Soil NH_4 Concentrations

	Supplemental Inorganic Fertilizer				
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	—— mg kg^{-1} ——	
C1	56	0	0	281	15
C1	112	0	0	191	16
C2	0	0	0	270	14
C2	56	0	0	367	18
C2	84	0	0	284	13
C2	112	0	0	320	15
C2	112	0	112	305	21
C2	112	112	0	293	17
C3	0	0	0	291	21
C3	56	0	0	327	15
C3	84	0	0	269	14
C3	112	0	0	344	17
C3	112	0	112	294	18
C3	112	112	0	273	17
M	0	0	0	346	18
M	56	0	0	375	27
M	84	0	0	445	20
M	112	0	0	494	17
M	112	0	112	347	21
M	112	112	0	397	28
UC	0	0	0	149	17
IF	112	112	112	212	16

November 2003 Soil NH_4 Concentrations

	Supplemental Inorganic Fertilizer				
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}	
C1	56	0	0	79	9
C1	112	0	0	63	7
C2	0	0	0	101	12
C2	56	0	0	85	10
C2	84	0	0	63	9
C2	112	0	0	76	9
C2	112	0	112	54	8
C2	112	112	0	63	9
C3	0	0	0	97	11
C3	56	0	0	79	10
C3	84	0	0	94	8
C3	112	0	0	87	11
C3	112	0	112	97	7
C3	112	112	0	86	8
M	0	0	0	90	11
M	56	0	0	96	9
M	84	0	0	66	9
M	112	0	0	67	8
M	112	0	112	58	8
M	112	112	0	75	10
UC	0	0	0	42	7
IF	112	112	112	71	9

APPENDIX D

February 2003 Soil NO_3 Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	16	3	3
C1	112	0	0	12	3	3
C2	0	0	0	86	3	2
C2	56	0	0	63	5	4
C2	84	0	0	54	4	3
C2	112	0	0	47	4	3
C2	112	0	112	42	3	4
C2	112	112	0	37	4	3
C3	0	0	0	165	4	5
C3	56	0	0	137	9	3
C3	84	0	0	91	3	3
C3	112	0	0	133	4	4
C3	112	0	112	87	4	3
C3	112	112	0	90	4	3
M	0	0	0	98	3	2
M	56	0	0	101	4	3
M	84	0	0	98	8	3
M	112	0	0	88	4	3
M	112	0	112	46	3	4
M	112	112	0	45	8	3
UC	0	0	0	4	3	3
IF	112	112	112	2	4	3

November 2003 Soil NO_3 Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}		
C1	56	0	0	6	3	3
C1	112	0	0	17	7	9
C2	0	0	0	4	3	4
C2	56	0	0	6	3	3
C2	84	0	0	6	3	3
C2	112	0	0	9	4	5
C2	112	0	112	8	4	6
C2	112	112	0	6	3	3
C3	0	0	0	4	3	3
C3	56	0	0	7	3	3
C3	84	0	0	7	3	3
C3	112	0	0	9	4	4
C3	112	0	112	10	4	6
C3	112	112	0	7	4	5
M	0	0	0	5	3	2
M	56	0	0	8	3	3
M	84	0	0	8	4	4
M	112	0	0	10	4	5
M	112	0	112	11	5	7
M	112	112	0	10	5	6
UC	0	0	0	2	2	2
IF	112	112	112	1	3	3

APPENDIX E

February 2003 Soil P Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	51	5	2
C1	112	0	0	50	4	1
C2	0	0	0	106	3	2
C2	56	0	0	99	4	3
C2	84	0	0	133	5	3
C2	112	0	0	100	5	1
C2	112	0	112	133	5	1
C2	112	112	0	77	3	2
C3	0	0	0	217	5	2
C3	56	0	0	230	7	3
C3	84	0	0	273	5	2
C3	112	0	0	274	7	2
C3	112	0	112	203	11	3
C3	112	112	0	220	6	4
M	0	0	0	108	6	5
M	56	0	0	111	6	2
M	84	0	0	108	5	1
M	112	0	0	110	5	2
M	112	0	112	105	7	3
M	112	112	0	77	6	2
UC	0	0	0	22	3	2
IF	112	112	112	25	3	1

November 2003 Soil P Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	87	7	3
C1	112	0	0	62	7	2
C2	0	0	0	86	7	2
C2	56	0	0	71	5	1
C2	84	0	0	89	11	3
C2	112	0	0	58	8	3
C2	112	0	112	98	12	2
C2	112	112	0	67	9	3
C3	0	0	0	231	17	3
C3	56	0	0	185	14	2
C3	84	0	0	258	22	1
C3	112	0	0	192	11	6
C3	112	0	112	216	23	2
C3	112	112	0	209	17	5
M	0	0	0	61	12	3
M	56	0	0	38	10	2
M	84	0	0	37	8	3
M	112	0	0	34	10	4
M	112	0	112	66	12	3
M	112	112	0	44	8	3
UC	0	0	0	22	7	3
IF	112	112	112	31	6	2

APPENDIX F

February 2003 Soil K Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	151	76	136
C1	112	0	0	150	86	197
C2	0	0	0	232	91	142
C2	56	0	0	159	73	175
C2	84	0	0	203	101	171
C2	112	0	0	184	105	150
C2	112	0	112	164	79	119
C2	112	112	0	272	118	165
C3	0	0	0	379	174	159
C3	56	0	0	319	133	174
C3	84	0	0	314	148	159
C3	112	0	0	324	152	176
C3	112	0	112	250	134	168
C3	112	112	0	387	204	199
M	0	0	0	261	104	142
M	56	0	0	182	108	165
M	84	0	0	162	90	113
M	112	0	0	193	98	161
M	112	0	112	139	76	137
M	112	112	0	218	140	156
UC	0	0	0	146	66	177
IF	112	112	112	245	105	141

November 2003 Soil K Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	115	80	161
C1	112	0	0	85	68	166
C2	0	0	0	145	86	152
C2	56	0	0	83	76	159
C2	84	0	0	165	77	146
C2	112	0	0	86	70	158
C2	112	0	112	71	66	126
C2	112	112	0	251	124	171
C3	0	0	0	252	173	185
C3	56	0	0	132	87	170
C3	84	0	0	161	98	183
C3	112	0	0	134	85	175
C3	112	0	112	101	73	151
C3	112	112	0	321	160	233
M	0	0	0	149	88	168
M	56	0	0	98	74	166
M	84	0	0	79	61	129
M	112	0	0	83	67	150
M	112	0	112	73	63	153
M	112	112	0	256	125	167
UC	0	0	0	122	88	190
IF	112	112	112	215	116	140

APPENDIX G

February 2003 Soil Ca Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	2,240	935	1,800
C1	112	0	0	1,593	699	2,346
C2	0	0	0	2,362	645	1,972
C2	56	0	0	2,526	749	2,433
C2	84	0	0	3,172	689	1,860
C2	112	0	0	2,657	768	2,036
C2	112	0	112	2,803	711	1,605
C2	112	112	0	2,036	686	2,103
C3	0	0	0	5,344	643	1,825
C3	56	0	0	4,825	800	2,267
C3	84	0	0	5,337	637	1,747
C3	112	0	0	5,910	800	2,160
C3	112	0	112	3,895	847	2,254
C3	112	112	0	4,419	627	2,365
M	0	0	0	2,250	692	2,010
M	56	0	0	2,527	748	1,962
M	84	0	0	2,277	742	1,627
M	112	0	0	2,077	689	2,151
M	112	0	112	1,744	597	1,932
M	112	112	0	1,618	675	1,803
UC	0	0	0	635	646	2,105
IF	112	112	112	557	586	1,967

November 2003 Soil Ca Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	2,980	834	1,933
C1	112	0	0	2,835	746	1,996
C2	0	0	0	2,676	592	1,919
C2	56	0	0	3,228	888	2,240
C2	84	0	0	3,145	823	1,784
C2	112	0	0	2,125	847	2,045
C2	112	0	112	2,776	868	1,650
C2	112	112	0	2,082	781	1,930
C3	0	0	0	5,836	792	1,813
C3	56	0	0	5,185	1213	2,286
C3	84	0	0	6,866	824	1,809
C3	112	0	0	5,603	858	2,218
C3	112	0	112	4,500	768	2,139
C3	112	112	0	5,957	775	2,345
M	0	0	0	2,045	675	1,891
M	56	0	0	1,470	787	1,934
M	84	0	0	1,532	607	1,568
M	112	0	0	2,338	715	1,990
M	112	0	112	1,960	697	2,095
M	112	112	0	1,927	640	1,763
UC	0	0	0	679	676	2,180
IF	112	112	112	373	412	1,666

APPENDIX H

February 2003 Soil Mg Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	168	90	167
C1	112	0	0	159	91	317
C2	0	0	0	252	83	261
C2	56	0	0	228	97	236
C2	84	0	0	253	91	212
C2	112	0	0	226	100	241
C2	112	0	112	230	90	117
C2	112	112	0	179	91	240
C3	0	0	0	388	77	209
C3	56	0	0	399	99	317
C3	84	0	0	413	87	199
C3	112	0	0	422	100	193
C3	112	0	112	324	107	286
C3	112	112	0	338	86	282
M	0	0	0	297	85	278
M	56	0	0	294	93	175
M	84	0	0	265	85	147
M	112	0	0	270	97	326
M	112	0	112	255	92	171
M	112	112	0	212	90	262
UC	0	0	0	106	76	223
IF	112	112	112	66	82	334

November 2003 Soil Mg Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K$_2$O	P$_2$O$_5$	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	166	108	183
C1	112	0	0	109	94	244
C2	0	0	0	211	92	226
C2	56	0	0	169	117	176
C2	84	0	0	172	101	203
C2	112	0	0	122	114	229
C2	112	0	112	122	102	130
C2	112	112	0	114	92	215
C3	0	0	0	357	109	198
C3	56	0	0	273	132	316
C3	84	0	0	294	128	192
C3	112	0	0	231	128	193
C3	112	0	112	203	124	274
C3	112	112	0	214	116	273
M	0	0	0	213	94	254
M	56	0	0	145	111	162
M	84	0	0	132	95	144
M	112	0	0	121	117	275
M	112	0	112	124	119	183
M	112	112	0	141	99	239
UC	0	0	0	113	87	193
IF	112	112	112	52	68	254

APPENDIX I

February 2003 Soil S Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	94	27	26
C1	112	0	0	70	25	25
C2	0	0	0	94	27	30
C2	56	0	0	135	27	28
C2	84	0	0	123	25	27
C2	112	0	0	123	24	30
C2	112	0	112	123	28	27
C2	112	112	0	98	27	26
C3	0	0	0	152	25	28
C3	56	0	0	155	28	28
C3	84	0	0	149	26	23
C3	112	0	0	174	27	28
C3	112	0	112	137	28	29
C3	112	112	0	139	27	28
M	0	0	0	127	28	28
M	56	0	0	137	26	27
M	84	0	0	161	25	24
M	112	0	0	177	24	30
M	112	0	112	126	26	27
M	112	112	0	140	24	25
UC	0	0	0	52	20	27
IF	112	112	112	57	26	26

November 2003 Soil S Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	44	20	20
C1	112	0	0	45	27	22
C2	0	0	0	49	23	21
C2	56	0	0	43	23	23
C2	84	0	0	49	23	16
C2	112	0	0	42	23	21
C2	112	0	112	44	22	19
C2	112	112	0	53	22	19
C3	0	0	0	57	28	19
C3	56	0	0	46	22	23
C3	84	0	0	57	24	19
C3	112	0	0	59	22	20
C3	112	0	112	44	20	21
C3	112	112	0	54	26	20
M	0	0	0	43	23	17
M	56	0	0	43	24	18
M	84	0	0	44	24	19
M	112	0	0	52	25	22
M	112	0	112	41	26	23
M	112	112	0	54	22	17
UC	0	0	0	42	25	20
IF	112	112	112	41	25	19

APPENDIX J

February 2003 Soil Cu Concentrations

	Supplemental Inorganic Fertilizer				
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}	
C1	56	0	0	0.29	0.29
C1	112	0	0	0.32	0.28
C2	0	0	0	0.22	0.28
C2	56	0	0	0.28	0.32
C2	84	0	0	0.31	0.28
C2	112	0	0	0.28	0.26
C2	112	0	112	0.31	0.33
C2	112	112	0	0.26	0.24
C3	0	0	0	0.22	0.26
C3	56	0	0	0.34	0.25
C3	84	0	0	0.31	0.27
C3	112	0	0	0.31	0.29
C3	112	0	112	0.28	0.29
C3	112	112	0	0.33	0.23
M	0	0	0	0.35	0.25
M	56	0	0	0.40	0.30
M	84	0	0	0.40	0.23
M	112	0	0	0.40	0.25
M	112	0	112	0.37	0.34
M	112	112	0	0.33	0.26
UC	0	0	0	0.26	0.28
IF	112	112	112	0.24	0.26

November 2003 Soil Cu Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K$_2$O	P$_2$O$_5$	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}	
C1	56	0	0	0.21	0.25
C1	112	0	0	0.25	0.24
C2	0	0	0	0.19	0.18
C2	56	0	0	0.19	0.27
C2	84	0	0	0.25	0.24
C2	112	0	0	0.19	0.24
C2	112	0	112	0.30	0.26
C2	112	112	0	0.24	0.23
C3	0	0	0	0.26	0.24
C3	56	0	0	0.24	0.19
C3	84	0	0	0.26	0.22
C3	112	0	0	0.26	0.17
C3	112	0	112	0.20	0.28
C3	112	112	0	0.26	0.22
M	0	0	0	0.26	0.24
M	56	0	0	0.25	0.26
M	84	0	0	0.31	0.24
M	112	0	0	0.35	0.25
M	112	0	112	0.41	0.28
M	112	112	0	0.30	0.23
UC	0	0	0	0.27	0.25
IF	112	112	112	0.20	0.20

APPENDIX K

February 2003 Soil Fe Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K$_2$O	P$_2$O$_5$	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	*mg kg^{-1}*	
C1	56	0	0	47	29
C1	112	0	0	56	26
C2	0	0	0	31	33
C2	56	0	0	29	26
C2	84	0	0	37	34
C2	112	0	0	33	31
C2	112	0	112	28	28
C2	112	112	0	38	25
C3	0	0	0	23	27
C3	56	0	0	32	27
C3	84	0	0	24	35
C3	112	0	0	23	29
C3	112	0	112	24	33
C3	112	112	0	30	35
M	0	0	0	31	30
M	56	0	0	33	35
M	84	0	0	34	26
M	112	0	0	32	30
M	112	0	112	32	38
M	112	112	0	35	33
UC	0	0	0	63	25
IF	112	112	112	61	32

November 2003 Soil Fe Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K$_2$O	P$_2$O$_5$	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}	
C1	56	0	0	44	42
C1	112	0	0	64	42
C2	0	0	0	50	49
C2	56	0	0	34	37
C2	84	0	0	65	52
C2	112	0	0	54	43
C2	112	0	112	58	41
C2	112	112	0	59	48
C3	0	0	0	33	45
C3	56	0	0	37	36
C3	84	0	0	35	40
C3	112	0	0	43	37
C3	112	0	112	33	42
C3	112	112	0	42	52
M	0	0	0	38	52
M	56	0	0	42	49
M	84	0	0	58	49
M	112	0	0	66	52
M	112	0	112	65	50
M	112	112	0	59	49
UC	0	0	0	92	43
IF	112	112	112	73	51

APPENDIX L

February 2003 Soil Mn Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K_2O	P_2O_5	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}	
C1	56	0	0	10	33
C1	112	0	0	11	32
C2	0	0	0	11	32
C2	56	0	0	13	36
C2	84	0	0	9	25
C2	112	0	0	12	28
C2	112	0	112	12	33
C2	112	112	0	10	22
C3	0	0	0	10	24
C3	56	0	0	15	20
C3	84	0	0	14	26
C3	112	0	0	12	28
C3	112	0	112	12	29
C3	112	112	0	14	22
M	0	0	0	17	25
M	56	0	0	16	25
M	84	0	0	17	18
M	112	0	0	19	25
M	112	0	112	13	39
M	112	112	0	13	22
UC	0	0	0	13	32
IF	112	112	112	8	33

November 2003 Soil Mn Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K$_2$O	P$_2$O$_5$	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}	
C1	56	0	0	16	27
C1	112	0	0	12	28
C2	0	0	0	13	36
C2	56	0	0	15	29
C2	84	0	0	15	24
C2	112	0	0	12	26
C2	112	0	112	17	31
C2	112	112	0	14	28
C3	0	0	0	18	22
C3	56	0	0	19	19
C3	84	0	0	20	21
C3	112	0	0	16	25
C3	112	0	112	12	22
C3	112	112	0	13	22
M	0	0	0	17	27
M	56	0	0	14	27
M	84	0	0	15	28
M	112	0	0	16	29
M	112	0	112	16	37
M	112	112	0	15	28
UC	0	0	0	14	36
IF	112	112	112	8	36

APPENDIX M

February 2003 Soil Zn Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K_2O	P_2O_5	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}	
C1	56	0	0	3	0.2
C1	112	0	0	3	0.3
C2	0	0	0	3	0.2
C2	56	0	0	2	0.2
C2	84	0	0	3	0.2
C2	112	0	0	2	0.2
C2	112	0	112	3	0.2
C2	112	112	0	2	0.1
C3	0	0	0	2	0.2
C3	56	0	0	4	0.3
C3	84	0	0	3	0.2
C3	112	0	0	3	0.2
C3	112	0	112	3	0.4
C3	112	112	0	3	0.2
M	0	0	0	3	0.2
M	56	0	0	5	0.2
M	84	0	0	4	0.2
M	112	0	0	3	0.2
M	112	0	112	3	0.3
M	112	112	0	3	0.3
UC	0	0	0	3	0.1
IF	112	112	112	1	0.1

November 2003 Soil Zn Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K$_2$O	P$_2$O$_5$	0-5 cm	5-15 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	mg kg^{-1}	
C1	56	0	0	2	0.2
C1	112	0	0	3	2.0
C2	0	0	0	2	0.2
C2	56	0	0	3	0.2
C2	84	0	0	3	0.2
C2	112	0	0	2	0.3
C2	112	0	112	3	0.2
C2	112	112	0	3	0.3
C3	0	0	0	4	0.4
C3	56	0	0	4	0.3
C3	84	0	0	4	0.3
C3	112	0	0	4	0.3
C3	112	0	112	3	0.4
C3	112	112	0	4	0.3
M	0	0	0	3	0.4
M	56	0	0	3	0.5
M	84	0	0	3	0.2
M	112	0	0	3	0.3
M	112	0	112	4	0.4
M	112	112	0	3	0.4
UC	0	0	0	3	0.2
IF	112	112	112	2	0.2

APPENDIX N

February 2003 Soil Na Concentrations

Treatment	Supplemental Inorganic Fertilizer N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	387	357	360
C1	112	0	0	367	361	356
C2	0	0	0	330	372	410
C2	56	0	0	393	331	370
C2	84	0	0	369	353	392
C2	112	0	0	356	339	398
C2	112	0	112	355	330	390
C2	112	112	0	344	371	349
C3	0	0	0	393	350	376
C3	56	0	0	395	396	438
C3	84	0	0	377	370	360
C3	112	0	0	387	366	389
C3	112	0	112	373	370	392
C3	112	112	0	359	353	391
M	0	0	0	368	362	389
M	56	0	0	377	342	361
M	84	0	0	365	357	364
M	112	0	0	416	379	372
M	112	0	112	364	346	385
M	112	112	0	406	369	382
UC	0	0	0	361	337	340
IF	112	112	112	332	344	388

November 2003 Soil Na Concentrations

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		mg kg^{-1}	
C1	56	0	0	284	292	271
C1	112	0	0	332	263	306
C2	0	0	0	318	272	272
C2	56	0	0	306	257	260
C2	84	0	0	310	278	281
C2	112	0	0	352	275	311
C2	112	0	112	333	289	262
C2	112	112	0	355	270	268
C3	0	0	0	354	297	289
C3	56	0	0	299	311	322
C3	84	0	0	333	275	264
C3	112	0	0	365	299	282
C3	112	0	112	311	275	300
C3	112	112	0	341	270	286
M	0	0	0	345	255	317
M	56	0	0	292	277	277
M	84	0	0	336	272	269
M	112	0	0	369	270	289
M	112	0	112	283	303	272
M	112	112	0	350	294	274
UC	0	0	0	330	269	270
IF	112	112	112	314	271	275

APPENDIX O

February 2003 Soil EC

Treatment	Supplemental Inorganic Fertilizer N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}	dS m^{-1}		
C1	56	0	0	0.36	0.04	0.05
C1	112	0	0	0.33	0.04	0.07
C2	0	0	0	0.64	0.04	0.05
C2	56	0	0	0.59	0.05	0.06
C2	84	0	0	0.58	0.05	0.07
C2	112	0	0	0.46	0.05	0.05
C2	112	0	112	0.40	0.04	0.06
C2	112	112	0	0.37	0.04	0.06
C3	0	0	0	0.68	0.05	0.07
C3	56	0	0	0.80	0.07	0.07
C3	84	0	0	0.60	0.05	0.06
C3	112	0	0	0.87	0.05	0.07
C3	112	0	112	0.64	0.05	0.06
C3	112	112	0	0.75	0.06	0.07
M	0	0	0	0.75	0.05	0.05
M	56	0	0	0.63	0.06	0.05
M	84	0	0	0.87	0.06	0.05
M	112	0	0	0.75	0.05	0.06
M	112	0	112	0.57	0.05	0.06
M	112	112	0	0.55	0.07	0.06
UC	0	0	0	0.17	0.03	0.06
IF	112	112	112	0.23	0.05	0.06

November 2003 Soil EC

	Supplemental Inorganic Fertilizer					
Treatment	N	K_2O	P_2O_5	0-5 cm	5-15 cm	15-30 cm
	kg ha^{-1} cutting^{-1}		kg ha^{-1} yr^{-1}		dS m^{-1}	
C1	56	0	0	0.20	0.14	0.11
C1	112	0	0	0.19	0.16	0.20
C2	0	0	0	0.21	0.17	0.13
C2	56	0	0	0.16	0.18	0.10
C2	84	0	0	0.19	0.14	0.13
C2	112	0	0	0.17	0.11	0.17
C2	112	0	112	0.17	0.21	0.13
C2	112	112	0	0.21	0.15	0.15
C3	0	0	0	0.25	0.17	0.15
C3	56	0	0	0.20	0.11	0.14
C3	84	0	0	0.23	0.14	0.16
C3	112	0	0	0.24	0.13	0.16
C3	112	0	112	0.17	0.15	0.16
C3	112	112	0	0.25	0.14	0.17
M	0	0	0	0.18	0.09	0.17
M	56	0	0	0.16	0.14	0.10
M	84	0	0	0.15	0.15	0.19
M	112	0	0	0.16	0.14	0.15
M	112	0	112	0.21	0.19	0.14
M	112	112	0	0.23	0.17	0.22
UC	0	0	0	0.19	0.13	0.16
IF	112	112	112	0.16	0.09	0.17

VITA

Thomas J Helton, son of Tommy and Brenda Helton, was born in Austin, Texas on May 27, 1978. He graduated from Burnet High School in Burnet, Texas in May of 1996. He received a Bachelor of Science Degree in agronomy from Texas A&M University, College Station, Texas in May of 2001. Upon graduation, he began his Master of Science graduate program at Texas A&M University, College Station, Texas, with Dr. Mark McFarland, Professor and Extension Soil Fertility and Water Quality Specialist. His permanent address is at his parent's home at 200 Stirrup, Burnet, Texas 78611.