Bermudagrass Production and Nutrient Uptake when Substituting Broiler Litter Nitrogen with Mineral Nitrogen

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Abstract

Achieving adequate hay production from hybrid bermudagrass [*Cynodon dactylon* (L.) Pers.] when plant P nutrition is the basis for broiler litter application rates will require supplementation with mineral nitrogen (N) fertilizer. The objective of this research was to determine yield and uptake of N and P in hybrid 'Coastal' bermudagrass fertilized with different rates of broiler litter in combination with applications of ammonium nitrate (34-0-0). Plots (4 x 6 m) were established at Mize, MS in a pasture with 30+ year history of litter and soil test P (STP, by Mehlich III analysis) of about 409 kg P ha^{-1}, and at Newton, MS in a pasture with no litter history and STP of about 52 kg P ha^{-1}. Broiler litter rates of 0, 4.5, 8.9, 13.4, and 17.9 Mg ha^{-1} were obtained by monthly applications of 4.5 Mg ha $^{-1}$ beginning in April, and these rates were supplemented, respectively, with 67 kg ha^{-1} mineral N (the highest rate beginning in April) in order to achieve 269, 202, 134, 67, and 0 kg N ha^{-1}. Thus, the annual N requirement of bermudagrass of about 269 kg N ha^{-1} was first met with broiler litter and then with mineral N. Treatments, including an unfertilized 'check', were repeated on the same plot areas in 1999, 2000, and 2001. Because forage dry matter (DM) was consistently low in unfertilized bermudagrass, averaging 12% (Newton) and 55% (Mize) of the highest average yield, these data were often used for comparison only. When analysis of variance was conducted without the 'check' plots, treatment difference in forage dry matter (DM) and P uptake were significant at Newton ($P<0.01$), but not at Mize ($P>0.50$). A significant treatment by year interaction was detected for yield and P uptake at both sites, primarily because these traits were greater in 2001 than 1999 and 2000 due to increased rainfall. At Newton, fertilization with only mineral N led to 2.0-3.0 Mg ha^{-1} lower DM as compared to other treatments, and the 8.9 Mg litter + 134 kg N treatment appeared to maximize DM and nutrient uptake. At Mize, forage yield and P concentration ≥90% of maximum relative yield were obtained from 4.5 Mg + 202 kg N treatment. Results indicate broiler litter rates should not exceed 8.9 Mg ha^{-1} yr^{-1} and be supplemented with mineral N to meet the crop N requirement. Although pasture N fertilization is costly, the practice may minimize environmental impacts when litter nutrients, particularly P, are applied in excess of crop needs.

Keywords: Bermudagrass, Nitrogen Management, Phosphorus Management, Poultry Waste

Introduction

The poultry industry in Mississippi produces about 450,000 Mg (500,000 tons) of broiler litter annually (Morgan and Murray, 2002). This product, a mixture of manure, wasted feed, and bedding materials, is commonly used as fertilizer on pasture and hay fields, particularly in south central Mississippi where broiler production is concentrated. A large proportion of this acreage is devoted to growing bermudagrass [*Cynodon dactylon* (L.) Pers.] for hay and grazing (Lang and Broome, 2003). Land application of litter has traditionally been limited to forage N requirements to minimize potential N leaching to ground water. But the difference in average N-P-K ratio in the litter (2.1:1:1.3) (Sims and Wolf, 1994) and the observed nutrient uptake ratio by hybrid bermudagrass at 90% of maximum yield (9:1:6) (Robinson, 1996), means that using litter as the sole nutrient source will increase soil test phosphorus (STP) (Sharpley, 1999). Accumulation of P in pasture soils has received increased attention from potential eutrophication it causes when receiving waters are P-limited (Daniel et al., 1994). As a result, regulatory agencies are moving to consider allowable litter application rates on crop P needs and site-specific STP concentrations (USEPA, 1996). The agronomic and environmental soil P threshold strategies suggested by the USDA and USEPA provide narrow, often incomplete, assessments of the risk of P losses, since variables other than soil P concentration control losses from field and landscapes (Sims, 2000). Thus, site-specific management strategies must be developed to minimize the nutrient discharge to the surface water by reducing system inputs of P in manure-producing areas.

When plant P nutrition is the basis for broiler litter rates, producing adequate quantities of high quality bermudagrass hay will require supplementation with mineral N fertilizer, a practice that may also enhance plant uptake of P (Adams, 1980). Evers (2002) found that supplementing broiler litter with mineral N fertilizer increased dry matter yield and uptake of P and K in Coastal bermudagrass. Complex relationships exist between forage productivity, nutrient recovery, soils, and farmer options, such as changes in manure nutrient application rate/time and crop system management. With good management practices, hybrid bermudagrass can remove about 45 kg P ha^{-1} $year^{-1}$ or more if water is not limiting growth (Evers, 1998). At yield levels of 14-16 Mg ha^{-1} on a previously manure-impacted site, hybrid bermudagrass removed about 50 kg ha^{-1} yr^{-1}, which was less than half of the P applied in litter at rates of 9 and 18 Mg ha^{-1} (Brink et al., 2002). In that study, annual P uptake was not affected by timing of litter application, perhaps due to already high STP levels, but applications in April and June to coincide with favorable growth temperatures appeared to maximize P uptake. It is apparent that depending on soil P bioavailability, timing mineral N applications to substitute for broiler litter N could be important for increased utilization of fertilizer nutrients by bermudagrass (Evers, 2002). Mismanagement of manure nutrients is more likely with hybrid bermudagrass hay production, which responds favorably to increasing rates of organic or inorganic N sources (Overman et al., 1993; Osborne et al., 1999) and to intensive harvest management (Overman et al., 1990). Hay production certainly has a place in remediation of high STP situations, as STP is decreased through removal of harvested hay or silage from the site (Novak and Chan, 2000; Pant et al., 2004). In these situations, lower rates of broiler litter supplemented with mineral N fertilizer are more appropriate.

Sistani et al. (2004) noted pasture soils receiving long-term broiler litter applications will likely accumulate excess P and some micronutrients (Cu and Zn) unless the principal components of nutrient management are used: (i) continuous soil test monitoring, (ii) proper litter application rate, and (iii) crop management to maximize nutrient uptake and removal. Therefore, information is needed on how to account for broiler litter N in order to use this manure efficiently and safely. Among Midwest corn producers, the average rate of N applied before soil sampling was 137 kg N ha^{-1} for manured soils and 150 kg N ha^{-1} for soils that did not receive animal manures. A difference in rate is expected because growers have long been advised to give credit for N in manure when selecting N fertilization rates (USDA, NRCS, 1999). The approximate difference in average rates of 15 kg N ha^{-1} is much smaller than would occur if growers believed the manure application rates were large enough to supply adequate N for crop growth. The relatively small credit for N in animal manures is consistent with the results of surveys of farming practices (Nowak et al., 1998), which show that most farmers make little or no downward adjustment in fertilization rates to account for N applied as animal manure.

Forage producers need comparative information regarding mineral fertilizer or manure N efficiency to improve farm profitability and minimize agricultural impacts on water quality (Chambers et al., 2000; Sims et al., 2000). The present research was conducted to (i) determine if substituting mineral N (NH_4NO_3) for broiler litter N would increase P uptake (= forage biomass x nutrient concentration) in 'Coastal' bermudagrass hay fields with different STP levels, and (ii) determine the appropriate combination of mineral-N and litter-N treatments to maximize forage yield and nutrient uptake.

Materials and Methods

Studies were conducted in 1999, 2000, and 2001 in existing swards of 'Coastal' hybrid bermudagrass at two sites in south central Mississippi. One site near Mize, MS on a Savannah fine sandy loam (fine-loamy, siliceaous, semiactive, thermic Typic Fraqiudults) was on a commercial farm. The second site on a Ruston fine sandy loam (fine-loamy, siliceaous, semiactive, thermic Typic Paleudults) was at the MAFES Coastal Plain Experiment Station near Newton, MS. The Mize pasture site is typical of many in the region where broiler litter has been applied to bermudagrass on an N basis (about 9.0 Mg ha^{-1} yr^{-1}) for many years. In contrast, the Newton pasture has no known history of broiler litter application. Soils were sampled at 0- to 5-cm and 5- to 15-cm depths in March 1999 prior to first litter application, and in May 2001 prior to the end of experiment (Table 1).

The bermudagrass sward was cleared of any weeds or senesced plant material in early Spring 1999. The 4- by 6-m plots were arranged in a randomized complete block design with four replicates. The fertilizer treatments were five combinations of broiler litter and mineral fertilizer that would meet bermudagrass N requirement of 269 kg N ha^{-1} (for an expected yield level of 9 Mg ha^{-1}) and unfertilized check (Table 2). Treatments were repeated on the same plot areas each year. At Mize, broiler litter was obtained from a nearby broiler house at each application time. At Newton, litter from a broiler house was delivered in spring each year and stored outdoors on a concrete floor under a polyethylene cover. Subsamples of broiler litter were obtained for nutrient determination prior to each application. In general, the chemical composition changed little for either source, so results from April were used to represent an approximate average of what was applied to plots (Table 3).

Broiler litter was applied by hand on a "as is basis". Annual broiler litter rates of 0, 4.5, 8.9, 13.4, and 17.9 Mg ha^{-1} were obtained by monthly applications of 4.5 Mg ha^{-1} beginning in April, and these litter rates were supplemented, respectively, with 67 kg ha^{-1} mineral N (the highest rate beginning in April) that applied 269, 202, 134, 67, and 0 kg N ha^{-1} as NH_4NO_3 (34% N) as a substitute for N not applied in broiler litter (Table 2). Thus, bermudagrass N requirement of 269 kg N ha^{-1} was first met with broiler litter and then with mineral N. Providing 50% of N is mineralized, a rate of 17.9 Mg ha^{-1} would meet the expected annual N requirement (Tables 2 and 3). The amount of mineralizable N supplied by broiler litter in the first season of application is based on total N analysis of litter and on certain assumptions (Cabrera and Gordilla, 1995).

Forage harvests began in late May to early June, at approximately a 30-d interval depending on rainfall and forage growth. Plots were harvested five times in 1999, three times in 2000, and four times in 2001. Forage dry matter (DM) yield was determined by cutting a 1- by 6-m swath at a 7-cm stubble height through the center of each plot using a sickle-bar mower. Subsamples (600-800 g) of forage were dried at 65 °C for 48 h and the dry weight recorded. The dry forage was ground to pass a 1-mm screen, sealed in plastic containers, and subsequently analyzed for mineral nutrients. Forage nutrient uptake was calculated as the product of DM yield and nutrient concentration at each harvest, and values were summed across all harvests. Efficiency of N and P uptake for the growing season was calculated as total uptake divided by the total quantity in the litter only. Analysis of variance was used to determine treatment differences in DM yield and nutrient uptake using PROC MIXED and PROC GLM procedures in SAS (Littell et al., 1996). Because unfertilized plants were consistently low yielding, data from these 'check' plots were sometimes excluded from analysis of variance in order to gain greater precision in separating differences among the five fertilizer treatments. A probability level of $P \leq 0.05$ was considered significant.

The following chemical analyses were performed on samples of soil, broiler litter, and bermudagrass hay. Soil and litter pH was measured using 10 g sample mixed in 10 ml water. Soil, litter and plant total N and total C were determined from duplicate subsamples using an automated dry combustion analyzer (Model NA 1500 NC, Carlo Erba, Milan, Italy). The concentration of P, K, Ca, Cu, Fe, Mg, Mn, and Zn in forage was determined from duplicate subsamples using emission spectroscopy on an inductively coupled argon plasma spectrometer (ICP, Thermo Jarrell Ash Model 1000 ICAP, Franklin, MA) following procedures described by Sistani et al (2004). Soils were extracted following Mehlich 3 procedures (Mehlich, 1984) and the extracts analyzed for P, K, Ca, Cu, Fe, Mg, Mn, and Zn using ICAP. The Mississippi State Soil Testing Lab routinely uses Lancaster method for nutrient analysis. Cox (2001) compared Mehlich 3 and Lancaster methods in various soils collected from eight fields in Mississippi and found weak correlation for soil P ($r=0.38$), though they gave similar results up to about 57 mg P kg^{-1}, beyond which Mehlich 3 extracted more P. The initial soil chemical properties for the present study are presented in Table 1.

Results and Discussion

The initial STP value based on Mehlich III analysis of 0-15 cm depth was about 8-fold greater at Mize than Newton (409 vs. 52 kg ha^{-1}) (Table 1). This result was expected due to long-term application of broiler litter at Mize before establishment of our experimental plots. The soil at Mize also had greater amounts of total N, and plant available K, Cu, Mn, and Zn. As expected, the amounts of N, P, and K applied to the soil surface increased four-fold as litter rate increased from 4.5 to 17.9 Mg ha^{-1} (Table 4). While the different sources of broiler litter provided similar amounts of total N at both sites, about 20-60 more units of P and K were provided at Mize than Newton. Assuming half of the total P is mineralized in the first year, the 4.5 Mg ha^{-1} rate provided sufficient P to maintain hybrid bermudagrass yields of 8.9-13.4 Mg ha^{-1} (Lang and Broome, 2003). There is little literature available on K in litter, but assuming 100% is plant available, the 13.4 Mg ha^{-1} litter application rate provided sufficient K for maximum hay production. Hybrid bermudagrass has high annual K requirements (Brink et al., 2003). At the Newton site in 2001, K uptake exceeded N uptake by bermudagrass receiving litter rates of 8.9, 13.4 and 17.9 kg ha^{-1}. Heavy usage of soil K in Coastal bermudagrass is also apparent from consistently greater K uptake in the broiler litter only treatment, as compared to mineral N only treatment that added no K over three years.

At Newton, rainfall followed closely the historical pattern except for lower monthly rainfall in July all three years, and large rainfall accumulation in March and September 2001 (Fig. 1). Similarly, rainfall at Mize followed closely the 30-yr mean, except in 2001 when heavier than normal rainfall was recorded in March, June, August and September. Forage DM yields were lower in 2000 than 1999 (Fig. 2) even though annual rainfall amounts were similar. This difference may be explained by above average rainfall in April 2000 that possibly washed some of the litter or fertilizer from the plots. Rainfall in 2001 was about 18% above the long-term average at both sites (Fig. 1). Consequently, DM yield and N uptake were significantly greater in 2001 than either 1999 or 2000 (Figs 2 and 3.), with 2000 experiencing some droughty, summer conditions. Across all treatments in 2001, total N uptake averaged about 259 kg ha^{-1} at Newton and 409 kg ha^{-1} at Mize. Lower N uptake at Newton was associated with 50% lower total N content in soil, as well as somewhat lower N concentration in the litter, as compared to soil and litter at Mize (Tables 1 and 3). Because annual rainfall was similar at both sites, factors other than soil moisture apparently limited bermudagrass yield and N uptake at Newton.

When unfertilized checks were excluded, annual forage DM averaged 13.7 Mg ha^{-1} at Mize (range: 7.8-21.1 Mg ha^{-1}) and 12.5 Mg ha^{-1} at Newton (range: 6.6-19.5 Mg ha^{-1}). With adequate fertilizer, Coastal bermudagrass may yield 11.2 to 13.4 Mg of hay per hectare (5-6 tons $acre^{-1}$) (Lang and Broome, 2003). Forage DM yield at Mize did not differ significantly across the five fertilizer treatments (Fig. 2), which might be expected due high soil nutrient levels observed initially due to long-term litter applications. Forage DM yield at Newton was lowest in bermudagrass fertilized with mineral N only, a treatment that produced significantly low yields in 2000 and 2001 (Fig. 2). Relatively high DM yields were obtained using 4.5 kg litter and 202 kg N ha^{-1} and did not differ from the other litter treatments in 1999 and 2001. Applying 8.9 Mg litter led to increased DM yield under droughty conditions in 2001. While these results at Newton may refute our hypothesis that 269 kg N ha^{-1} would meet N requirement of 'Coastal' bermudagrass, they do illustrate the value of poultry litter as a soil amendment and nutrient source for bermudagrass.

The treatment by year interaction was significant for forage DM at both sites (Fig. 2). This interaction resulted from greater DM production in 2001 than either 1999 or 2000 and from variable DM yields obtained at 17.9 Mg ha^{-1} litter. With increased rainfall in 2001, the highest litter rate of 17.9 Mg ha^{-1} led to high DM accumulation, and high N and P uptake in bermudagrass (Figs. 2, 3 and 4). Increased rainfall at Mize led to slightly greater DM accumulation and nutrient uptake in bermudagrass fertilized with a combination of 13.4 Mg litter and 67 kg N ha^{-1} (Figs. 2, 3 and 4). Similar to forage DM, the treatment by year interaction was significant for total uptake of N and P in bermudagrass.

Analysis of variance across years without unfertilized 'check' plots found significant difference in DM yield and P uptake between N fertilizer treatments at Newton ($P<0.01$), but not at Mize ($P>0.50$) (Figs 2 and 4). As mentioned above, the treatment by year interaction was significant for total N and P uptake at both Newton ($P<0.01$) and Mize ($P<0.05$). We found moderate rates of poultry litter of 4.5-8.9 kg ha^{-1} in combination with mineral N fertilization led to high nutrient uptake, particularly in drier years of 1999 and 2000. This result supports studies showing N supplementation of broiler litter N in bermudagrass has potential to improve yield and plant nutrient uptake (Evers, 2002). The timing of mineral N additions may also be important to P uptake in bermudagrass, as Sistani et al. (2004) found total soil N and P decreased during the maximum uptake in late spring and summer in heavily-manured Ruston soil. Soil moisture is another factor that influences growth and nutrient uptake in bermudagrass, with N or P concentration often inversely related to forage DM accumulation. In the present study, tissue P concentration was consistently greater in unfertilized 'checks' than plants fertilized with litter or/and mineral N (data not shown), but yields were least in unfertilized plants. Total uptake of P was maximal at about 60 kg ha^{-1} in 2001 in the litter only treatment of 17.9 Mg ha^{-1}, when rainfall was above average and plants accumulated the most forage DM (Fig. 2). Brink et al. (2002) reported annual P uptake ranged from 27-50 kg $ha^{-1}$when 18 Mg ha^{-1} broiler litter was applied to common and six hybrid bermudagrass cultivars on a heavily-manured Ruston soil at Mize, MS. Forage DM also was somewhat less in that study, ranging from about 9 Mg ha^{-1} in common bermudagrass to 19 Mg ha^{-1} in Alicia, Russell and Tifton 44 hybrids.

Broiler litter promotes biological and physical properties that make soil more productive and less erosive, but the risk of environmental impacts can be high when improper amounts of litter are applied (Han et al., 2000). In agreement with other manure rate studies (Brink et al., 2002; Brink et al., 2003), bermudagrass P recovery decreased as litter rate increased across the different treatments. Because manure was not used as the sole fertilizer source, results from this present study indicated N fertility per se can enhance P uptake in bermudagrass. Applications of 269 kg N ha^{-1} as 34-0-0 increased P uptake by 10-20 kg ha^{-1} at Mize and by 10-14 kg ha^{-1} at Newton (Fig. 4). In combination with broiler litter, the potential for mineral N to maximize P uptake was evident at Newton in 2000 only, when the 4.5 Mg litter + 202 kg N ha^{-1} treatment removed about 25 more kg P ha^{-1} than mineral N only treatment. The increase in P uptake by this treatment is certainly of environmental benefit since the amount of P applied at 8.9 Mg ha^{-1} (167-200 kg ha^{-1}) exceeds the observed maximum uptake rate. At Mize, soils had high concentration of nutrients and heavy metals, as well as high N content that apparently precluded significant treatment differences in yield or nutrient uptake when mineral N was substituted for litter N.

Nutrient uptake in forage grasses is primarily a function of plant biomass, but varies due to differences in weather, cultivar, soil properties, and management practice (McLaughlin et al., 2004). Burns et al. (1985) reported 'Coastal' hybrid bermudagrass receiving 670 kg N ha^{-1} and 153 kg P ha^{-1} from swine effluent removed an average of 382 kg N ha^{-1} and 43 kg P ha^{-1} yr^{-1}. In the present study, P uptake was closely associated with forage DM across the different treatments (n=24), and slightly stronger correlation was obtained at Mize (r = 0.92-0.98) than at Newton (r = 0.86-0.92). This positive relationship would largely explain treatment difference in P uptake by bermudagrass, because tissue P concentration is stable relative to other nutrients (Brink et al., 2002; Evers, 2002). Plant uptake of N and other minerals increased with increasing rainfall, illustrating the impact of rainfall on hay production and nutrient recovery. At Newton, N recovery by plants fertilized with 269 kg ha^{-1} mineral N only relative to check plots was 45% in 1999, 30% in 2000, and 57% in 2001. At Mize, the corresponding values for N recovery were 38% in 1999, 15% in 2000, and 52% in 2001. The somewhat greater N recoveries at Newton than Mize appear to reflect a larger N limitation on growth due to less total N in soil (Table 1). In general, these results support evidence that crop yield and N uptake are directly related to the amount of N fertilizer applied (Pant et al., 2004) and nutrient recovery is enhanced under favorable growth conditions and perhaps more frequent harvests (Brink et al., 2002).

Conclusions

With respect to year and N fertility effects, our results are similar to those for bermudagrass grown in a swine effluent spray field (McLaughlin et al., 2004). In that study, DM yield and nutrient uptake appeared to be enhanced from increased rainfall, and hence soil moisture, and from additional N supplied in the swine-effluent. Overall, our results support the use of mineral N fertilizer in a nutrient management plan when broiler litter is applied to hybrid bermudagrass hay field, including high STP situations. A grower needs to consider local soil and climate conditions to ensure maximum nutrient uptake, and begin applying litter or fertilizer to pasture when daytime temperatures are about 24-27 °C, a range considered favorable for bermudagrass growth (Brink et al., 2002). Although fertilizing pasture with mineral N source is costly, the practice may minimize environmental impacts when broiler litter nutrients, particularly P, Cu, and Zn, are applied in excess of crop needs. Nitrogen application rates and sources, however, should be carefully determined to avoid soil acidification.

At Mize, a site with high STP and high soil N, the mineral N only treatment and the 4.5 Mg ha^{-1} litter + 202 kg ha^{-1} N treatment had high yield and P uptake in the relatively dry years of 1999 and 2000. This suggests that the use of mineral N fertilizer in high STP situations may lead to increased soil P availability when soil moisture conditions are less favorable for growth. For instance, we did not observe a significant yield response to mineral N substitution when rainfall increased in 2001, suggesting the soil or the plant process was not N limited.

At Newton, a site with no known litter history, substituting mineral N at litter rates of either 4.5 or 8.9 Mg ha^{-1} produced the most forage that sometimes removed more soil nutrients than bermudagrass fertilized with mineral N only. Applying 269 kg N ha^{-1} from mineral N only did not produce hay yields comparable to plants fertilized with a combination of broiler litter and mineral N fertilizer. This illustrates the value of poultry litter as a soil amendment and nutrient source for bermudagrass production. Therefore, when plant P nutrition is the basis for broiler litter application rates, bermudagrass growth and P uptake can be enhanced by organic amendments to soil, as well as timely applications of a readily available mineral N source. Because substituting mineral N for litter N stimulated P uptake at Newton, knowledge of average N content of litter and mineralization rate of that N will improve our knowledge of how to manage broiler litter applications based on forage P requirement. The amount of mineralizable N supplied by litter in the first season of application is typically estimated from analytical N content of the litter and on certain assumptions (Cabrera and Gordillo, 1995). To avoid uncertainty it may be necessary to empirically determine a rate that results in plant growth and productivity equivalent to that of conventional fertilizer (Westerman et al., 1988). Broiler litter has potential for rapid nutrient mineralization rate which may pose a risk of nutrient loss and leaching in pastures when applied in early spring or late fall (Cabrera et al., 1994).

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Tables and Figures

Table 1. Soil pH, total nitrogen (TN), and concentration of selected minerals (by Mehlich 3 extraction) at 0-5 and 5-15 cm depths in Spring 1999 before applying broiler litter to bermudagrass pastures at Newton, MS and Mize, MS.

Site and Depth (cm)	pH	TN	P	K	Ca	Mg	Cu	Fe	Mn	Zn
		------- $g\ kg^{-1}$ -------					------- $mg\ kg^{-1}$ -------			
Newton										
0 – 5	5.9	1.30	0.05	0.06	1.35	0.12	2	159	104	3
5 – 15	6.1	0.53	0.01	0.04	0.82	0.06	1	124	93	1
Mize										
0 – 5	5.8	2.34	0.23	0.23	0.82	0.11	13	102	214	16
5 – 15	5.9	0.60	0.16	0.10	0.47	0.05	4	95	206	3

Table 2. Treatment combinations applied to bermudagrass in order to substitute broiler litter N with mineral fertilizer (NH_4NO_3, 34-0-0). Based on average N content in litter and mineralization rate of that N, applying 17.9 kg litter ha^{-1} would meet annual N requirement of 269 kg ha^{-1}. A rate of 4.5 kg litter ha^{-1} is expected to meet annual P requirement.

Broiler Litter Application	Litter Rate	Mineral N Application	Total N Rate[a, b] (Litter-N + NH_4NO_3-N)	
4.5 Mg $month^{-1}$		67 kg $month^{-1}$	Newton	Mize
	Mg ha^{-1}		------- kg ha^{-1} -------	
Apr, May, Jun, Jul	17.9		300	315
Apr, May, Jun	13.4	Jul	291	303
Apr, May	8.9	Jun, Jul	283	291
Apr	4.5	May, Jun, Jul	276	285
	0	Apr, May, Jun, Jul	269[b]	269[b]

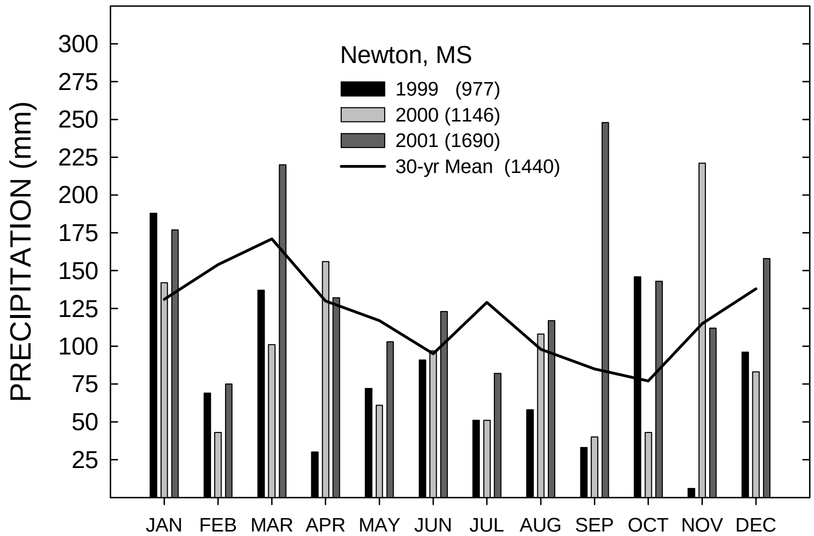
[a]Assumes 50% of N in litter is available for plant uptake during the first year.
[b]Assumes 100% of N applied as 34-0-0 is available for plant uptake.

Table 3. Broiler litter pH and concentration of selected minerals (by ICP-IOCEAS) in broiler litter applied as fertilizer to bermudagrass pastures in at Newton and Mize, MS in May 1999, 2000, and 2001.

		pH	N	P	K	Ca	Mg	Cu	Fe	Mn	Zn
			-------------------- g kg^{-1} ----------------					-------------- mg kg^{-1} ------------			
1999	Newton	7.4	35.7	17.6	25.8	26.6	5.4	621	1581	639	449
	Mize	7.5	38.3	24.2	31.3	31.0	7.7	838	832	837	591
2000	Newton	7.6	31.8	18.6	26.4	27.1	5.7	648	1985	692	496
	Mize	7.7	34.9	22.5	29.6	30.1	6.1	687	837	631	416
2001	Newton	7.5	33.1	20.1	26.7	26.8	6.0	496	2003	476	409
	Mize	7.4	32.5	20.8	29.1	30.9	6.4	541	1033	657	455

Table 4. Average amount of total nutrients in broiler litter applied at four rates in 1999, 2000 and 2001, based on average chemical analysis of nutrient in litter (Table 3.)

Site and Litter Rate	N	P	K	Cu	Zn
	------------------------------------ kg ha^{-1} ---------------------------------				
Newton					
4.5	150	84	118	2.6	2.0
8.9	300	168	236	5.3	4.0
13.4	450	252	354	7.9	6.0
17.9	600	336	471	10.5	8.1
Mize					
4.5	158	101	134	3.1	2.2
8.9	316	202	269	6.2	4.4
13.4	474	302	403	9.2	6.5
17.9	631	403	538	12.3	8.7



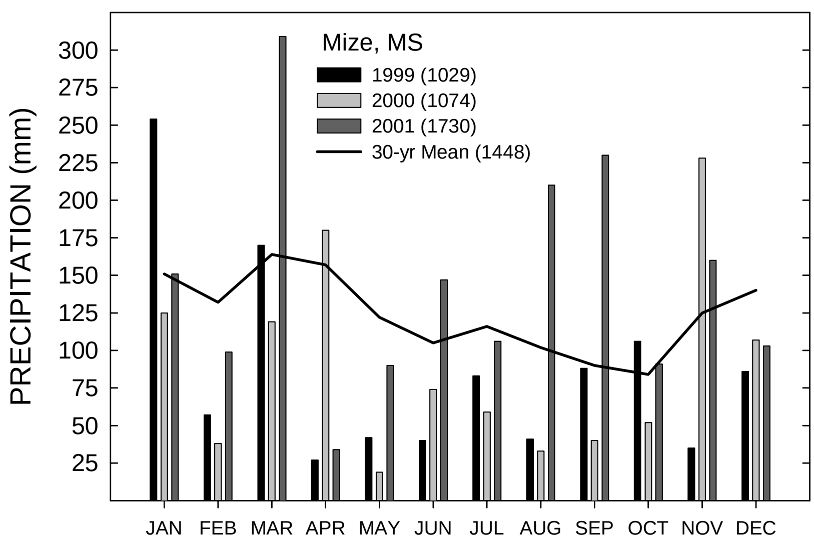
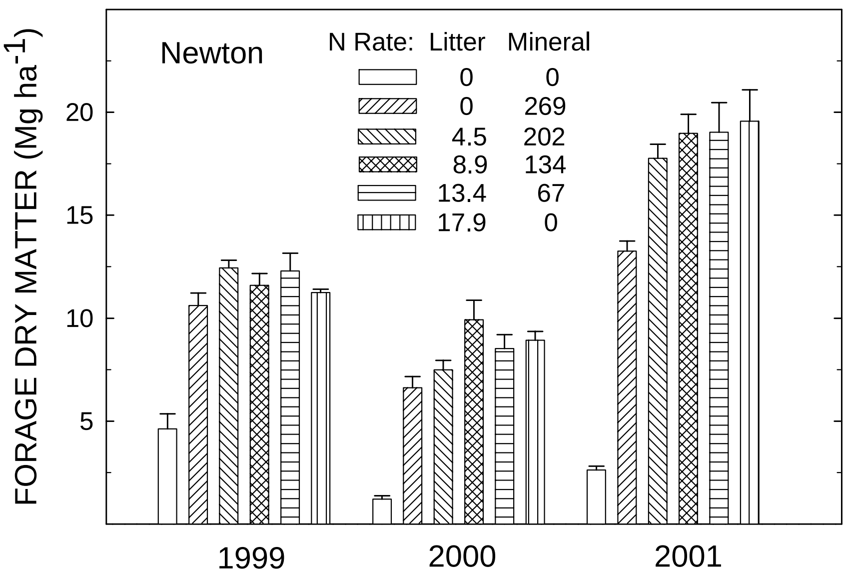


Figure 1. Monthly rainfall for 1999, 2000, and 2001, and long-term average rainfall. Cumulative amounts are presented in parenthesis.



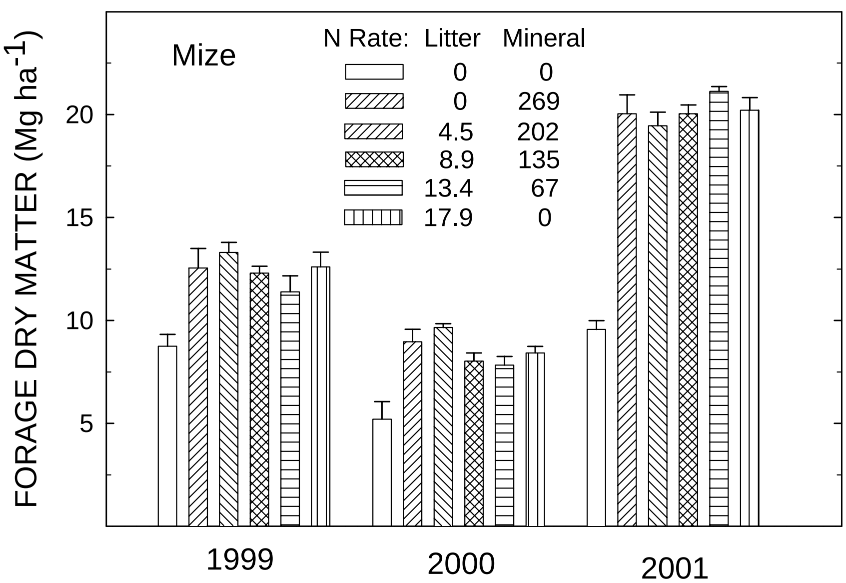


Figure 2. Annual forage dry matter (DM) yield of Coastal bermudagrass receiving broiler litter in combination with different rates of mineral N. Including the no litter and no mineral N treatment, values for LSD (P=0.05) at Newton were 1.77, 1.72 and 2.59 in 1999, 2000 and 2001, respectively. Values for LSD (P=0.05) at Mize were 1.90, 1.58 and 1.81 in 1999, 2000 and 2001, respectively.

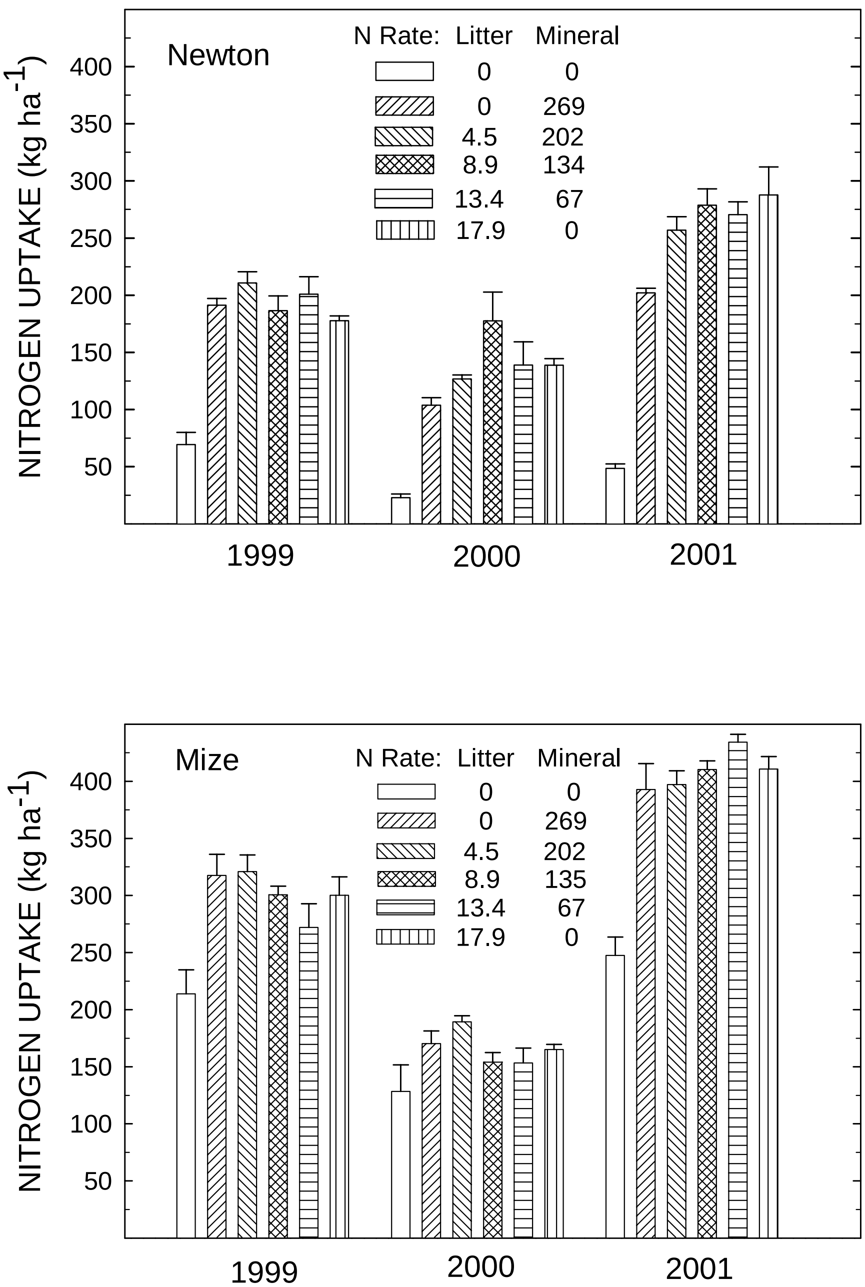


Figure 3. Annual nitrogen uptake in Coastal bermudagrass receiving broiler litter in combination with different rates of mineral N. Including the no litter and no mineral N treatment, values for LSD (P=0.05) at Newton were 32, 38, and 37 in 1999, 2000 and 2001, respectively. Values for LSD (P=0.05) at Mize were 43, 40 and 40 in 1999, 2000 and 2001, respectively.

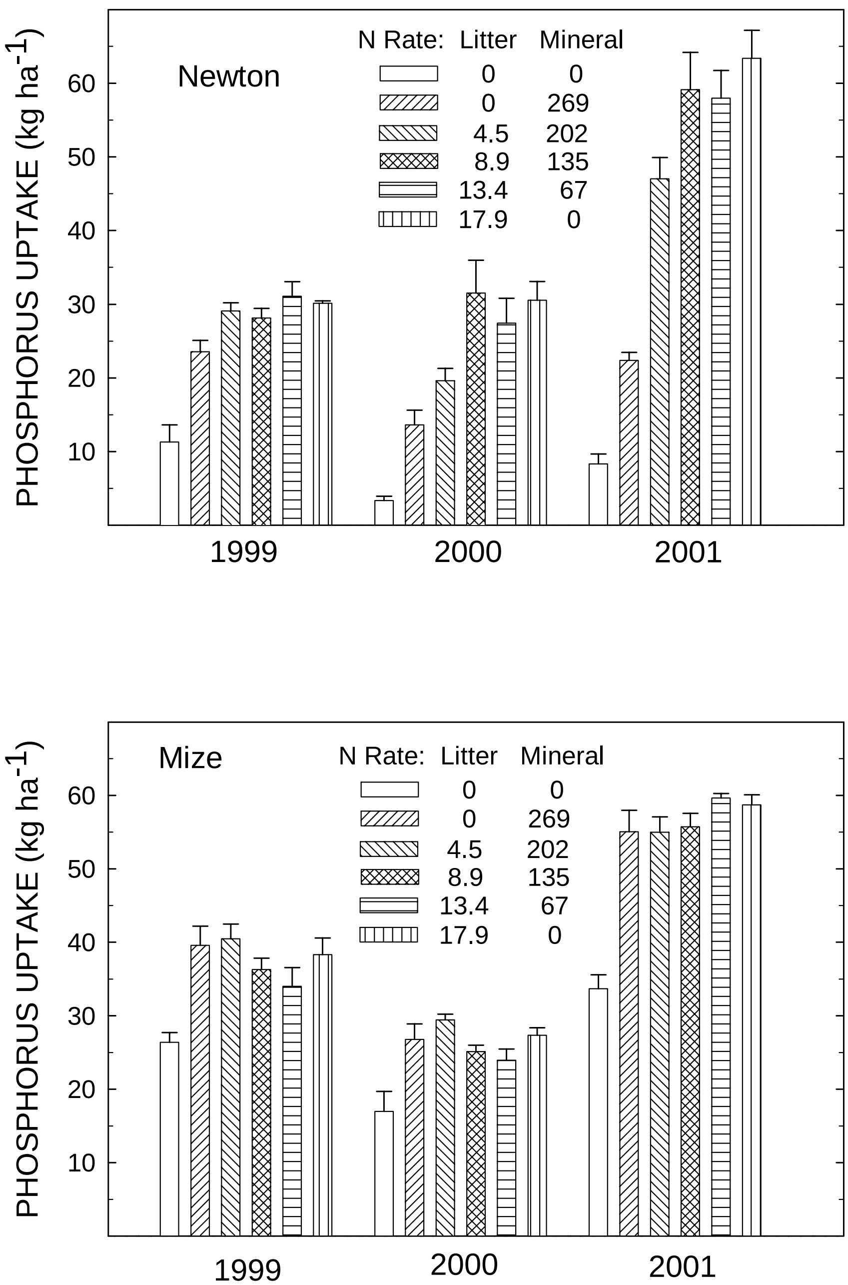
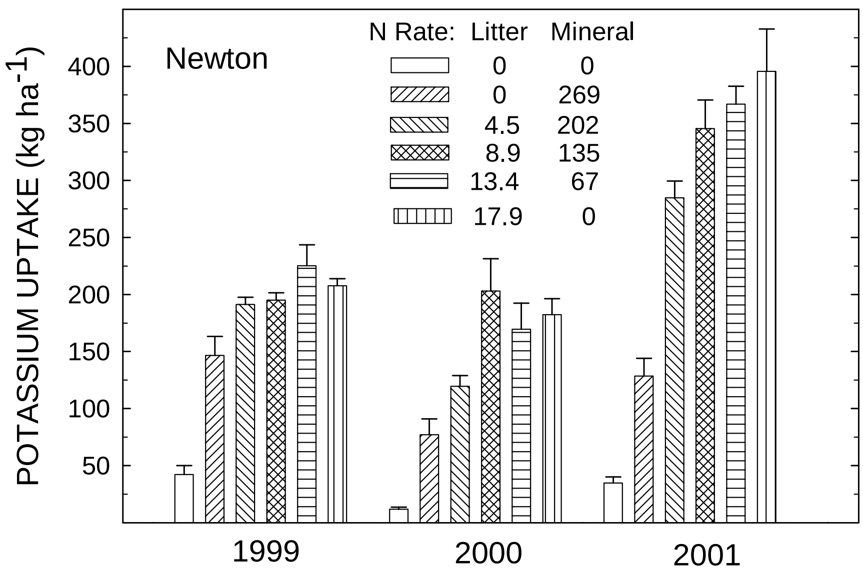


Figure 4. Annual phosphorus uptake in Coastal bermudagrass receiving broiler litter in combination with different rates of mineral N. Including the no litter and no mineral N treatment, values for LSD (P=0.05) at Newton were 4.8, 7.3 and 8.3 in 1999, 2000 and 2001, respectively. Values for LSD (P=0.05) at Mize were 5.7, 5.3 and 5.9 in 1999, 2000 and 2001, respectively



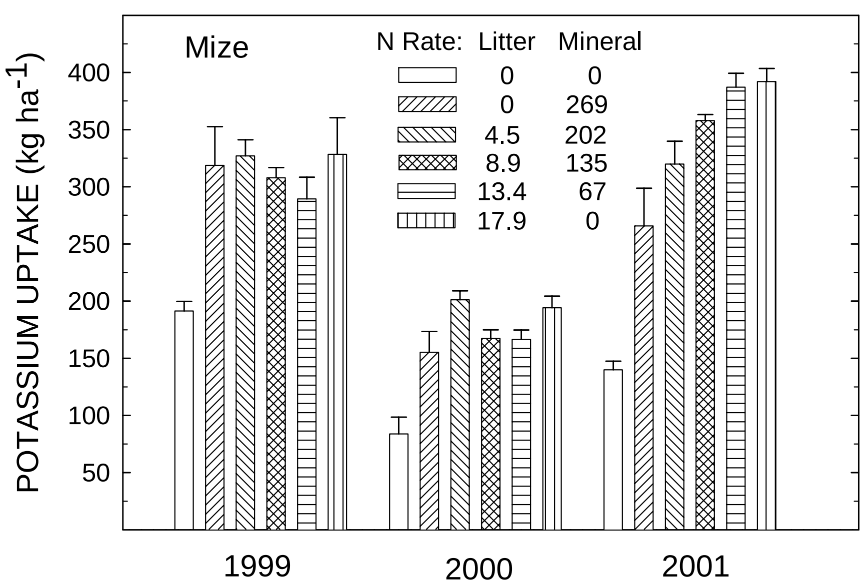


Figure 5. Annual potassium uptake in Coastal bermudagrass receiving broiler litter in combination with different rates of mineral N. Including the no litter and no mineral N treatment, values for LSD (P=0.05) at Newton were 38, 53 and 64 in 1999, 2000 and 2001, respectively. Values for LSD (P=0.05) at Mize were 67, 37 and 64 in 1999, 2000 and 2001, respectively.