RESEARCH

Broiler Litter vs. Ammonium Nitrate as Nitrogen Source for Bermudagrass Hay Production: Yield, Nutritive Value, and Nitrate Leaching

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ABSTRACT

The Lower Suwannee River Basin (LSRB) in northern Florida is environmentally sensitive. This study evaluated two surface-applied N sources for 'Tifton 85' bermudagrass (*Cynodon* spp.) hay production and associated risk of nitrate contamination of groundwater. The study was conducted at two locations in the LSRB where soils are deep, sandy Entisols. During a 2.5-yr period, bermudagrass received sole N source ammonium nitrate (AN), applied at 42, 84, 126, and 168 kg N ha^{-1} per growth interval, or sole N source broiler (chicken, *Gallus gallus domesticus*) litter (BL), applied at 84 and 126 kg N ha^{-1}. Plots were arranged using a randomized block design with three or four replications depending on the location. Suction-cup lysimeters were installed at a 1.4-m soil depth to monitor nitrate movement from the primary rooting zone. For AN, dry matter yield and crude protein (CP) concentration increased with an increase in N level, while forage P declined and in vitro digestible organic matter increased. Forage yield with BL was 64, 48, and 67% of yield with AN applied at common levels in 1998, 1999, and 2000, respectively. Forage CP was mostly less for BL than for AN, but forage P was greater for BL. A potential risk to groundwater quality due to nitrate leaching below the primary rooting zone was observed only with AN applied at 168 kg N ha^{-1}. Probable ammonia emissions from surface-applied BL, however, likely resulted in poorer bermudagrass production and could impact nearby surface waters.

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Abbreviations: AN, sole N source ammonium nitrate; ANBL, combination N source ammonium nitrate (50%) plus broiler litter (50%); BL, sole N source broiler litter; CP, crude protein; DM, dry matter; IVDOM, in vitro digestible organic matter; LSRB, Lower Suwannee River Basin; NDF, neutral detergent fiber; UFA, Upper Floridan Aquifer.

Nitrogen is the most limiting nutrient in the production of bermudagrass (*Cynodon* spp.) forage. Bermudagrass yield and forage crude protein (CP) concentration increase up to fertilizer N levels at or exceeding 670 kg ha^{-1} yr^{-1} (Prine and Burton, 1956; Burton et al., 1963; Day and Parker, 1985). Due to the high cost of N from commonly used commercial fertilizers, hay producers in the Lower Suwannee River Basin (LSRB) are seeking alternative sources. The LSRB is a major bermudagrass hay production area that supports beef (cow–calf) and dairy industries. The types of soils and underlying hydrogeology in the LSRB, make the Upper Floridan Aquifer (UFA) highly vulnerable to nitrate contamination. Most of the soils are well to excessively drained, deep, sandy Entisols with low organic matter and cation exchange capacity, and are highly prone to nutrient leaching, nitrate in particular. These types of soils are common in the Central Florida Ridge region (Fig. 1). Also, the UFA is relatively close to the surface and the unsaturated layers above the aquifer are generally thin and unconfined (Andrews, 1992). These characteristics coupled with relatively high annual rainfall and periodic heavy rainfall events, increase the possibility that nitrate from commercial fertilizers will reach groundwater. The Suwannee River is also vulnerable to nitrate pollution because during low flow, it is

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supplied with water from the UFA through springs and seeps (Andrews, 1992). Therefore, an evaluation of an alternative N source in the LSRB not only involves its effectiveness in the production of quality bermudagrass hay, but must include its nitrate leaching potential.

Broiler litter is an alternative N source available in the region. Numerous broiler operations are concentrated mainly in Suwannee and Lafayette counties in northern Florida (USDA-NASS, 2009). Although broiler litter contains other nutrients necessary for plant growth, it is likely that an "independent" hay producer (i.e., a producer not involved in broiler production) will consider the N concentration in broiler litter as more important than other macro plant nutrients, thereby applying it on an N basis. For independent hay growers, an evaluation of broiler litter as an N source needs to involve a direct comparison with other sources. Also, it should identify any potential weed problems. Many independent hay producers are concerned that broiler litter may contain viable weed seeds, which could lead to new weed species being introduced into their fields and a possible increase in herbicide costs.

Broiler litter applied to bermudagrass can benefit hay producers that own broiler houses in two ways. It can provide an avenue for disposal as well as nutrients for forage production. Therefore, it is likely that amounts of applied N will be much greater because the cost of the broiler litter is amortized partly by the broiler operation. The range of N applications used in the following study include those commonly applied to bermudagrass by independent hay producers in the LSRB (Woodard et al., 2006), as well as an application of 90 kg N ha^{-1} per growth cycle recommended by the Institute of Food and Agricultural Services (IFAS), University of Florida, Gainesville (Chambliss et al., 2006). The primary objective was to compare broiler litter with ammonium nitrate as surface-applied N sources for several aspects of bermudagrass hay production including dry matter (DM) yield, nutritive value, potential environmental impact, residual N, and potential weed problems.

MATERIALS AND METHODS

The experiment included two locations in the LSRB of northern Florida that had no previous history of broiler litter application (Fig. 1). Project sites were in Gilchrist County (29°50′ N, 82°52′ W) and Suwannee County (30°18′ N, 82°54′ W). These sites will be referred to as Gilchrist and Suwannee. At Gilchrist, the soil is an excessively drained Kershaw fine sand (thermic, uncoated Typic Quartzipsamment). The soil at Suwannee is a well-drained Foxworth fine sand (thermic, coated Typic Quartzipsamment). The average water table depth at Suwannee is 4 m below the soil surface. At Gilchrist, the water table is >7 m. Average monthly maximum and minimum temperatures and daily solar radiation for the area are presented in Fig. 2. Estimated date (50% probability) of the first freeze for the region is 25 November and of the last freeze is 10 March (Bradley, 1983).

'Tifton 85' bermudagrass was planted with sprigs in March 1998 at both locations. This grass is an interspecific *Cynodon* hybrid developed by USDA-ARS at the Coastal Plain Experiment Station in Tifton, GA (Burton et al., 1993). Plots were arranged using a randomized block design with three blocks at Gilchrist and four blocks at Suwannee. Each plot was 15.2 by 15.2 m in size. Also in March, two suction lysimeters were installed per plot at a depth of 1.4 m below the soil surface, which was considered below the primary rooting zone. The lysimeters were constructed by attaching a round-bottom, porous ceramic cup (5.1-cm o.d. by 6-cm length, 0.1 MPa high flow; Soil Moisture Equipment Corporation, Santa Barbara, CA) to the end of 4.9-cm o.d. polyvinyl chloride tubing. To establish the bermudagrass, a blended fertilizer was applied across all plots in April 1998, which supplied 45, 5, and 19 kg ha^{-1} of N, P, and K, respectively. By mid-July, the bermudagrass was approximately 80% established. The plots were then staged by removing the top growth and treatments were initiated.

Fertilizer Treatments and Harvest Dates

In northern Florida, the growing season begins in April and ends in October. The research was conducted without irrigation. Bermudagrass without irrigation is generally harvested three to four times by local hay producers during the growing season (Woodard et al., 2006). For each growth period, treatments consisted of N fertilizer applications of (i) 42, 84, 126, and 168 kg N ha^{-1} from sole source ammonium nitrate (AN), (ii) 84 and 126 kg N ha^{-1} from sole source broiler litter (BL), and (iii) 84 and 126 kg N ha^{-1} with one half of the N from ammonium nitrate and one half from broiler litter (ANBL). The total amount of N applied each year depended on the number of harvests made during the growing season. Treatment fertilizers were surface-applied at the start of each growth period. For plots receiving AN, P and K were applied at 15 and 56 kg ha^{-1} per growth period, respectively, using a blended fertilizer that included micronutrients. For BL and ANBL treatments, there was enough P in the broiler litter to supply a minimum of 15 kg P ha^{-1} per growth period. Broiler litter that provided 126 kg N ha^{-1} per growth period contained enough K to supply a minimum level of 56 kg K ha^{-1} per growth period. Other treatments involving broiler litter were fertilized with the appropriate amount of potassium chloride to bring applied K levels up to 56 kg ha^{-1} per growth period. Granular fertilizers were applied using a walk-behind fertilizer spreader (LESCO Inc., Rocky River, OH).

Each plot receiving broiler litter was subdivided into a grid containing nine sections. The appropriate amount of litter was weighed for each section and surface-applied manually. Given the average DM and N concentrations in broiler litter (Table 1), the 84 kg N ha^{-1} application of BL required an average of 3.0 Mg ha^{-1} of broiler litter "as applied," while the 126 kg N ha^{-1} application required 4.5 Mg ha^{-1}. Amounts of actual N applied per growth period at the Gilchrist and Suwannee sites for BL and ANBL during the 1998, 1999, and 2000 seasons are shown in Table 2.

The first half of the 1998 growing season was considered an establishment phase for the bermudagrass. The harvest schedule during the experiment was similar to that used by hay producers and based mainly on plant height, which relates to sufficient yield to justify the expense of harvesting and the time required to solar dry the forage before baling. There were two growth periods

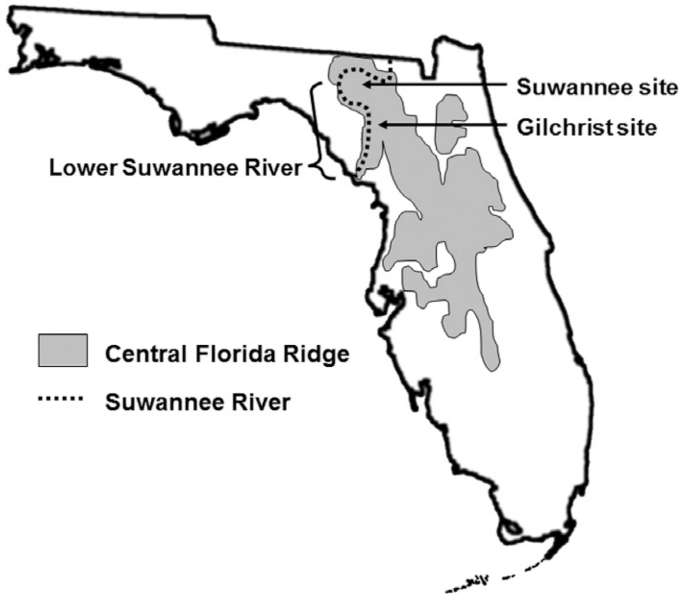

Figure 1. Location of research sites along the lower Suwannee River and in the Central Ridge region of Florida. The Central Florida Ridge is dominated by well-drained to excessively drained sandy soils.

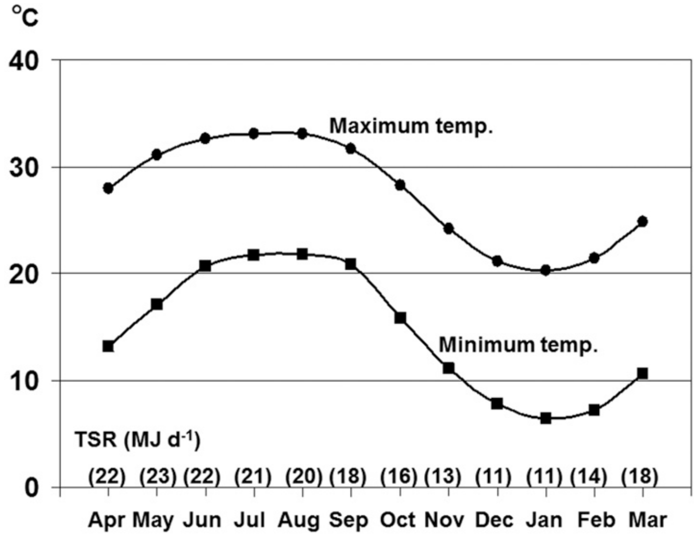

Figure 2. Monthly average minimum and maximum daily temperatures (1961–1990) and daily total solar radiation (TSR: 1955–1987) recorded at the University of Florida's Green Acres Agronomy Farm near Gainesville, FL. Green Acres is 45 km east-southeast of the Gilchrist site.

during the latter half of the 1998 season when the bermudagrass received treatments. Fertilizers were applied on 14 July and 31 August at Gilchrist and 23 July and 24 September at Suwannee. The bermudagrass was harvested on 18 August and 29 October at Gilchrist and 10 September and 13 November at Suwannee. Forage DM yield will be the only forage response shown for 1998.

In 1999, there were four growth periods. At both sites, the first fertilizer application occurred in early April, while the second, third, and fourth applications occurred shortly after the first, second, and third harvests, respectively. Harvest dates were 15 June, 13 August, 16 September, and 5 November for Gilchrist and 16 June, 11 August, 24 September, and 6 November for Suwannee. Due to low rainfall in 2000 (Fig. 3), there were only three growth periods. Broiler litter was applied in March, late May, and August at both sites, while ammonium nitrate was applied in April and shortly after the first and second harvests. Harvest dates were 13 July, 21 August, and 16 October for Gilchrist and 5 July, 14 August, and 9 October for Suwannee.

Broiler Litter Analysis

Broiler litter was purchased as needed from North Florida Holsteins Dairy near Bell, FL. At the dairy the litter was kept in a covered feed bunker and was continuously being mixed in rations for nonlactating animals. The broiler litter had gone through deep stack processing (Bucklin et al., 1997). Broiler litter samples were taken at the time of application. Within a growing season, the amount of broiler litter applied during later growth periods was adjusted according to the calculated amount of N applied previously. Average component concentration and low and high levels from 18 batches of broiler litter are shown in Table 1. For component analyses, litter samples were sent to the Dairy One DHI Forage Testing Laboratory in Ithaca, NY. Their analytical methods can be found in DHI Forage Lab analytical Procedures (DHI Forage Testing Laboratory, 1998). Their procedure for total N concentration involved a modified Kjeldahl digestion (AOAC method 984.13; AOAC International, 1999), followed by automatic distillation and titration using a Tecator Kjeltec Auto 1030 analyzer, [Tecator, Sweden; AOAC method 976.06 (G), (H)]. Minerals P, K, Ca, Mg, Na, Fe, Zn, Mn, Cu, and Mo were extracted with an acid solution (1.5 M HNO_3 plus 0.5 M HCl) and determined using inductively coupled plasma spectroscopy.

Lysimeter Sampling and Soil Water Analysis

Lysimeter sampling began in July 1998 and continued at 14-d intervals through March 2001. Data collected from July 1998 through March 1999 are not shown. During extended periods of the experiment, we were unable to obtain soil water samples from the lysimeters due to dry conditions. Nevertheless, an

Table 1. Components found in 18 batches of broiler litter surface-applied to bermudagrass during 1998, 1999, and 2000. The litter had been subjected to "deep stack" processing.

Component	Unit	Avg.	Min.	Max.
pH	—	7.3	6.7	8.3
Dry matter (DM)	g kg^{-1}	740	650	850
N	g kg^{-1} DM	38	28	45
P	g kg^{-1} DM	19	14	24
K	g kg^{-1} DM	25	15	31
Ca	g kg^{-1} DM	27	20	34
Mg	g kg^{-1} DM	5	3	6
S	g kg^{-1} DM	5	2	8
Na	g kg^{-1} DM	7	4	11
Fe	g kg^{-1} DM	2	0.8	5
Zn	mg kg^{-1} DM	369	209	465
Mn	mg kg^{-1} DM	350	191	454
Cu	mg kg^{-1} DM	229	46	313
Mo	mg kg^{-1} DM	6	4	9
Urea-N	g kg^{-1} DM	—	<0.02	0.86
Ammonium N	g kg^{-1} DM	8	3	11
Nitrate-N	g kg^{-1} DM	—	< 0.02	0.14
Ash	g kg^{-1} DM	290	180	600

Table 2. Target fertilizer N level and actual mean N levels applied per growth period for sole N source broiler litter (BL) and combination N source ammonium nitrate and broiler litter (ANBL) during the 1998, 1999, and 2000 growing seasons at the Gilchrist and Suwannee sites in northern Florida.

Location	N source	Target N	Avg. "actual" N level† 1998	1999	2000
		kg ha^{-1}			
Gilchrist	BL	84	86	84	94
	BL	126	129	125	141
	ANBL	84	85	84	89
	ANBL	126	127	125	133
Suwannee	BL	84	88	83	87
	BL	126	132	124	131
	ANBL	84	86	84	85
	ANBL	126	129	125	129

†Average N level applied per growth period within growing season. There were two growth periods in the latter half of the 1998 growing season, four growth periods during the 1999 season, and three during the 2000 season.

attempt to collect samples was made at 14-d intervals. Two days before sampling, any water contained in the lysimeter was evacuated before applying suction (40–45 kPa). At sampling, suctions were released. Samples were collected, acidified (≤2 pH), and placed in a cooler within 15 min. Lysimeters were also installed nearby in a low N-impacted area at each location. Nitrate-N concentration from these lysimeters was negligible during the experiment (≤0.4 mg L^{-1}; data not shown). Nitrate (plus nitrite-N) concentration in soil water collected with suction lysimeters was determined by EPA method 353.2 (USEPA, 1983), using a Flow IV, air-segmented, automated analyzer equipped with a spectrophotometer (O-I analytical, College Station, TX).

Forage Analysis

For DM yield determination, bermudagrass forage within a 7.2-m^2 section was harvested (3-cm stubble height) from each plot and weighed. A grab sample was taken and weighed (~1.5 kg), then dried at 60°C in a forced-air oven. Forage samples were then ground using a mill equipped with a 1-mm screen. Tissue N and P analyses involved a modification of the standard Kjeldahl procedure (Gallaher et al., 1975) followed by automated colorimetry (Hambleton, 1977) using a Technicon Auto analyzer (Technicon Instruments Corp., Tarrytown, NY). A modified two-stage technique by Moore and Mott (1974) was used to determine in vitro digestible organic matter (IVDOM) concentration. Ash-free neutral detergent fiber (NDF) concentration was determined using a procedure by Van Soest and Wine (1967) with modifications suggested by Golding et al. (1985).

Weed Ratings and Topsoil Total Nitrogen in 2001

Before land preparation began for the current study (October 1997), existing weed species were identified at both sites. The Gilchrist site was covered with a dense stand of various broadleaf weeds that were common to the area. Perennial grasses were not growing on the site. The Suwannee site was covered with a thick sod of bahiagrass (*Paspalum notatum* Flüggé). In the spring of 2001, the bermudagrass was allowed to grow naturally with no

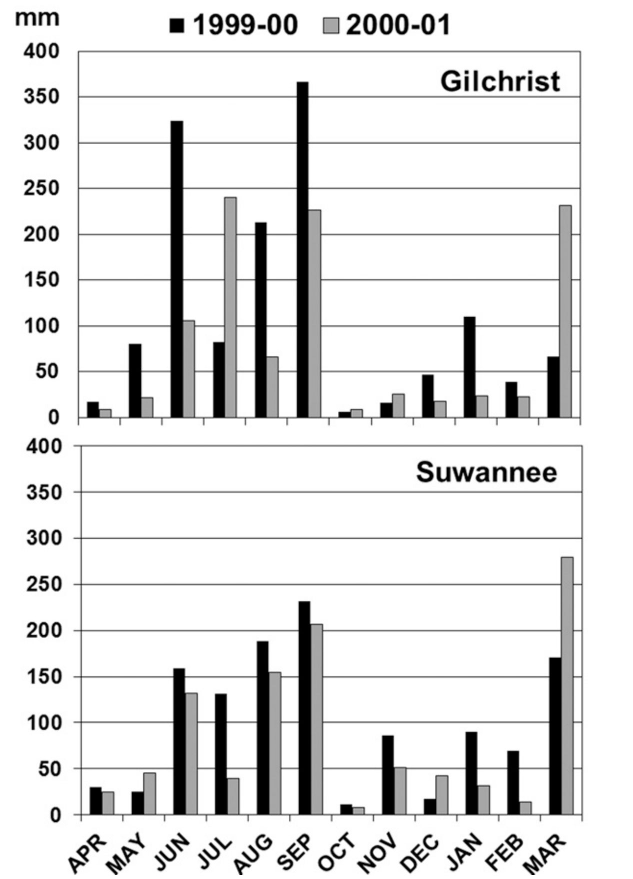

Figure 3. Monthly rainfall totals for Gilchrist and Suwannee locations from April 1999 to March 2001. For Gilchrist, growing season totals (April–October) were 1090 mm for 1999 and 680 mm for 2000. Season totals for Suwannee were 780 mm for 1999 and 610 mm for 2000.

fertilizers or herbicides being applied at either site. In July 2001, plots at Gilchrist were rated for area coverage of broadleaf weeds, while at Suwannee, plots were rated for coverage of bahiagrass. Two persons independently made area coverage ratings and their results were averaged. The weed coverage estimates involved a 1 to 5 rating, in which 1 represented almost no broadleaf weeds at Gilchrist or bahiagrass at Suwannee and 5 represented plots with the most weeds (i.e., about 15% broadleaf weed coverage at Gilchrist and 20% bahiagrass coverage at Suwannee).

In May 2001, the upper 7.6 cm of topsoil and the 7.6- to 15.2-cm underlying layer of topsoil were sampled at Gilchrist. A standard Kjeldahl procedure described by Bremner and Mulvaney (1982) was used to measure soil total N. The purpose was to explain any residual effects of the N source–level treatments on bermudagrass performance during the first half of the 2001 in which no fertilizers were applied. On 19 July 2001, the bermudagrass was harvested at Suwannee to determine DM yield, forage N, and forage N removal. Harvesting procedures and forage analysis were the same as previously described.

Statistical Analysis

Before statistical analysis, average means for forage CP, P, IVDOM, and NDF within a growing season were calculated on a weighted basis depending on DM yield of each harvest. Weed rating data were transformed using the SAS SQRT function.

Also, soil water nitrate N concentrations were averaged over 3-mo periods from April 1999 to March 2001. Responses were analyzed by fitting mixed effects models (Littell et al., 1996) using the PROC MIXED procedure of SAS (SAS Institute Inc., 1992). The effect of time (i.e., year or 3-mo period) was considered a repeated measure. A treatment effect was considered significant at $P < 0.05$, while interaction terms were significant at $P < 0.10$. To determine the nature of the effect of applied N level (AN only) on forage response, topsoil N concentration, and weed rating, contrasts for linear and quadratic effects were examined and considered to be significant at $P < 0.05$. To compare the effect of all fertilizer N source–level treatment combinations on response variables, pairwise comparisons of means were made with the Least Significant Difference method using Student's *t* statistic at the 0.05 level of significance. Least squares means are reported.

Most data are reported by year because the number of harvests per season varied. Also, forage response and nitrate N concentration of soil water were averaged across the two locations because there were very few interactions involving location. Furthermore, our primary objective was to determine the impact of N source and amount applied on forage performance and other response parameters within a region (i.e., LSRB) with less emphasis on site-specific effects.

Table 3. Average dry matter yield per growth period for bermudagrass fertilized with different amounts and sources of fertilizer N during a 2.5-yr period. Yield was averaged over two locations in northern Florida.

N level†	N source‡	Year 1998	1999	2000
kg ha^{-1}		Mg ha^{-1}		
42	AN	4.0	2.7	3.3
84	AN	4.4	4.3	5.4
126	AN	5.2	4.8	6.6
168	AN	5.2	5.0	6.9
Polynomial effects for only AN source§		L**	L** Q**	L** Q**
84	BL	2.9	1.8	3.3
126	BL	3.2	2.6	4.7
84	ANBL	4.0	3.2	4.7
126	ANBL	4.7	4.1	5.8
LSD (0.05) for N level–N source comparisons within a column		0.6	0.5	0.4

**Significant at the 0.01 level.

†Level is the amount of N applied per growth period. There were two growth periods in the latter half of 1998 season, four periods during the 1999 growing season, and three periods in the 2000 season.

‡AN, sole N source ammonium nitrate; BL, sole N source broiler litter; ANBL, combination N source ammonium nitrate plus broiler litter with each source supplying 50% of the N.

§For AN only, linear (L) and/or quadratic (Q) effects are significant with increasing N level.

RESULTS AND DISCUSSION

Ammonium Nitrate and the Effect of Applied Nitrogen on Forage Performance

Forage DM yield per harvest increased as the amount of applied N increased in each year but the rate of increase was different causing a year × N level interaction ($P < 0.01$; Table 3). In 1998, yield increased only 1.2 Mg from the lowest to the highest amount of N applied, likely due to the influence of additional N from corn residues and weeds at Gilchrist and a heavy bahiagrass sod at Suwannee, both of which were previously plowed under during land preparation. In the two succeeding years, DM yield of the highest N application was nearly double that of the lowest level of applied N. The rate at which yield increased, however, declined with fertilizer N level. Similar findings have been reported for bermudagrass by others (Day and Parker, 1985; Johnson et al., 2001; Silveira et al., 2007).

Nitrogen fertilizer level affected components of nutritive value differently (Table 4). The greatest effect was on CP concentration, which increased with increasing level of applied N. The rate at which forage CP improved either increased (1999) or remained constant (2000) with increasing N level. These results demonstrate the luxury consumption capacity of bermudagrass for N, which has been shown by others (Prine and Burton, 1956; Johnson et al., 2001; Silveira et al., 2007). Conversely, forage P concentration gradually declined with increasing fertilizer N application in both years. Albeit marginal, the decline in forage P with an increase in yield indicates a dilution effect. Most studies have shown forage P to remain unchanged with increased N application. Day and Parker (1985) reported that P concentration in 'Coastal' bermudagrass did not change with annual N applications ranging from 84 to 672 kg ha^{-1}. Fisher and Caldwell (1959) reported no significant differences in forage P concentration in Coastal bermudagrass with annual N applications ranging from 0 to 2016 kg ha^{-1}. However, they reported mean forage P concentrations of 2.6, 2.3, 2.2, and 2.1 g kg^{-1}, respectively, with annual N applications ranging from 112 to 672 kg ha^{-1} (similar annual amounts of N to the current study).

There was a marginal increase in IVDOM concentration with increasing N level (Table 4). From the lowest to the highest N level, mean IVDOM concentration throughout the 2-yr period increased by an average of only 20 g kg^{-1}. With Tifton 85 bermudagrass, Johnson et al. (2001) reported a quadratic response of forage IVDOM to increasing applications of N. Two-year IVDOM means were 580, 563, 560, 572, and 600 g kg^{-1} for N levels of 0, 39, 78, 118, and 157 kg ha^{-1} per growth period, respectively. In the current study, forage NDF was unaffected by applied N (data not shown), which is in contrast to the findings of Johnson et al. (2001). They reported a linear decrease in NDF with increasing amounts of applied N. In the present study, average NDF concentrations were less in 1999 (792 g kg^{-1}) than in 2000 (819 g kg^{-1}; $P < 0.01$), likely due to differences in plant maturity associated with the bermudagrass being harvested four times in 1999 and three times in 2000. Other forage components made evident that nutritive value was higher in 1999. Mean CP

Table 4. Average crude protein, P, and in vitro digestible organic matter (IVDOM) concentrations per growth period for bermudagrass fertilized with different sources and levels of N fertilizer during 1999 and 2000. Concentration was averaged over two locations in northern Florida.

N source†	N level‡	Crude protein		P		IVDOM	
		1999	2000	1999	2000	1999	2000
	kg ha^{-1}	g kg^{-1}					
AN	42	80	68	2.1	2.1	551	521
AN	84	95	81	2.0	1.8	553	527
AN	126	114	102	1.9	1.7	563	533
AN	168	139	127	1.8	1.7	569	543
Polynomial effects for only AN§		L**Q**	L**	L**	L**Q*	L**	NS
BL	84	83	84	2.7	2.7	546	551
BL	126	91	93	2.6	2.7	541	552
ANBL	84	88	78	2.1	2.1	550	540
ANBL	126	103	95	2.2	2.2	550	547
LSD (0.05) for pair-wise comparison among N source-N levels within a column		5	8	0.2	0.2	13	21

*Significant at the 0.05 level.

**Significant at the 0.01 level.

†AN, sole N source ammonium nitrate; BL, sole N source broiler litter; ANBL, combination N source ammonium nitrate plus broiler litter with each supplying 50% of the N.

‡Level is the amount of N applied per growth period. There were four growth periods in 1999 and three periods in 2000.

§For only AN, linear (L) and/or quadratic (Q) effects are significant with increasing N level. NS, not significant.

concentration was 107 g kg^{-1} in 1999 vs. 94 g kg^{-1} in 2000 ($P < 0.01$). Mean IVDOM concentration was 559 g kg^{-1} in 1999 vs. 531 g kg^{-1} in 2000 ($P < 0.01$).

Broiler Litter vs. Ammonium Nitrate

During the 2.5-yr period of the field experiment, DM yield of bermudagrass was markedly less in plots fertilized with BL compared with AN (Table 3). Bermudagrass yield for BL applied at 84 kg N ha^{-1} was less or similar to AN applied at 42 kg N ha^{-1}, depending on year. Yield from BL applied at 126 kg N ha^{-1} was consistently less than that of AN applied at 84 kg N ha^{-1}. Mean yields for the two N treatment levels of BL were 64, 48, and 67% of those for equal N levels of AN in 1998, 1999, and 2000, respectively. Mean yields for the two N treatment levels of ANBL were 91, 80, and 88% of those for equal N levels of AN in 1998, 1999, and 2000, respectively. With simple additive effects, yield for ANBL should be 82, 74, and 83% for 1998, 1999, and 2000, respectively. Somewhat greater percentages obtained for ANBL possibly imply a significant synergetic effect on bermudagrass performance when combining ammonium nitrate and broiler litter. One explanation for this response is that ammonium nitrate stimulated mineralization of N in broiler litter, thereby increasing its availability (Sikora and Enkiri, 2000).

Forage CP concentrations were generally greater for AN than BL, while those for ANBL were intermediate (Table 4). One exception was in 2000 with 84 kg N ha^{-1} when CP did not differ among the three N source treatments. For 126 kg N ha^{-1}, values averaged 16 g kg^{-1} more for AN than BL. In contrast, average concentration of forage P was considerably less for AN (1.9 g kg^{-1}) than BL (2.7 g kg^{-1}) at common levels of applied N. The average P concentration for ANBL was 2.2 g kg^{-1}. One explanation for greater forage P for the BL and ANBL sources is that less available N limited growth, thereby minimizing the effect of dilution. If this was true, similar or lower forage P concentrations would be expected for BL at 126 kg N ha^{-1} compared with AN at 42 kg N ha^{-1} because DM yield for BL at 126 kg N ha^{-1} was equal to (1999) or greater than (2000) that of AN at 42 kg N ha^{-1}. However, across both years, forage P for BL at 126 N was substantially greater (2.7 g kg^{-1}) than that of AN at 42 kg N ha^{-1} (2.1 g kg^{-1}). A more plausible explanation for greater forage P is that a greater amount of P was applied with BL. For each of the four levels of applied N for AN, plots received 15 kg P ha^{-1} per growth period, whereas for BL applied at 84 and 126 kg N ha^{-1}, plots received 42 and 63 kg ha^{-1} of accompanying P per growth period, respectively. For forage IVDOM concentration, there were opposing trends between years. In 1999, IVDOM concentration tended to be greater for AN than BL at common N applications, but in 2000 it tended to be less (Table 4). Differences in NDF concentration between N sources (data not shown) were not detected. Average NDF concentration for all fertilizer source-N level treatment combinations in 1999 and 2000 ranged from 785 to 824 g kg^{-1}.

Others have compared the effects of AN and BL on bermudagrass performance. In 1992, Evers (1998) surface-applied BL to Coastal bermudagrass at annual N applications of 320 and 640 kg ha^{-1} (each made as a single application or two split applications). Ammonium nitrate was applied at N levels ranging from 0 to 448 kg ha^{-1} (two split applications only). Using a quadratic equation describing the bermudagrass DM yield response to the ammonium nitrate N levels and

Table 5. Three-month average nitrate N concentration in soil water extracted from below the primary rooting zone (1.4-m soil depth) of bermudagrass that received sole N source ammonium nitrate (AN), combination N source ammonium nitrate plus broiler litter (ANBL), and sole N source broiler litter (BL) at various N levels per growth period. Concentrations were averaged across Gilchrist and Suwannee sites in northern Florida.

		1999–2000[†]				2000–2001			
N level	N source[‡]	Apr.–June	July–Sept.	Oct.–Dec.	Jan.–Mar.	Apr.–June	July–Sept.	Oct.–Dec.	Jan.–Mar.
kg ha^{-1}		mg kg^{-1}							
42	AN	<1b[§]	<1b	<1b	<1c	<1b	<1b	<1c	<1b
84	AN	<1b	<1b	<1b	2c	<1b	<1b	<1c	<1b
84	ANBL	<1b	<1b	<1b	1c	<1b	1b	<1c	<1b
84	BL	<1b	<1b	<1b	<1c	<1b	<1b	<1c	<1b
126	AN	<1b	<1b	<1b	22b	1b	6b	9b	4b
126	ANBL	<1b	<1b	1b	4c	<1b	2b	<1c	1b
126	BL	<1b	<1b	<1b	2c	<1b	<1b	<1c	<1b
168	AN	1b	5a	12a	65a	24a	48a	98a	54a

[†]A 12-mo cycle began in April and continued through March.

[‡]For combination N source ANBL, 50% of N applied came from ammonium nitrate and 50% from broiler litter.

[§]Three-month averages within a column with the same lowercase letter are not different ($P > 0.05$).

resulting yields from broiler litter N levels (dependent variable), he estimated that N availability of single broiler litter applications per season to be 60% for the 320 kg N ha^{-1} level and 62% for the 640 kg N ha^{-1} level. When broiler litter was applied in two splits, estimated N availability was less (i.e., 40 and 45%, respectively). These relative availabilities were reasonably consistent to those of the current study. To account for less N availability with broiler litter, Wood et al. (1993) fertilized 'Tifton 44' bermudagrass with ammonium nitrate at N levels of 112, 224, and 336 kg ha^{-1} yr^{-1} and compared them with broiler litter applied at annual N levels of 150, 300, and 600 kg ha^{-1}. The N levels for broiler litter were 34, 34, and 79% greater than those of ammonium nitrate, respectively. Though differences occurred within individual harvests, 2-yr DM yield averages did not differ between ammonium nitrate and broiler litter within each of the low, medium, and high levels of applied N. Also, CP concentration was similar between the two N sources.

Substantial N loss can occur from surface-applied broiler litter via ammonia volatilization (Wolf et al., 1987; Cabrera et al., 1993; Brinson et al., 1994), especially when application occurs during the hot summer months (Sharpe et al., 2004). Thus, it is likely that the lower bermudagrass yield and forage CP for BL in the current study were caused by a reduction in available N resulting from ammonia emissions at the soil surface. Other avenues for potential N loss include surface runoff and subsurface lateral drainage, denitrification, and nitrate leaching. Runoff and subsurface lateral drainage were likely minimal on the deep, sandy soils at both study sites. The permeability class for both soils is rapid. Loss of N via denitrification was also unlikely because of the well-drained to excessively drained, deep sands overlying a saturation zone >4 m below the soil surface (McNeal et al., 1995). However, nitrate leaching frequently occurs in these soils with applications of readily available commercial N sources.

Three-month average nitrate N concentration in soil water collected from suction lysimeters indicated that movement of nitrate below the primary rooting zone in BL plots from April 1999 through March 2001 was unlikely (Table 5). Nitrate leaching was also minimal for ANBL, as well as AN applied at 42 and 84 kg N ha^{-1}. However, greater nitrate N concentrations were detected during some periods for AN at 126 and 168 kg N ha^{-1}. With AN applied at 168 kg N ha^{-1} after each growth period, average nitrate N concentration was ≥48 mg kg^{-1} during four 3-mo periods, indicating substantial N movement out of the upper soil profile. Any N loss via leaching should be minimal for commercial N fertilizer sources applied to bermudagrass at the IFAS recommended level of 90 kg N ha^{-1} per growth period. Also, N loss by leaching should be low with the range of commercial fertilizer N levels applied by hay producers in the LSRB (N levels in producer's survey ranged from 65 to 105 kg ha^{-1} per growth period; Woodard et al., 2006). As a consequence, the impact on groundwater quality should be minimal.

The application of BL was clearly inferior to AN for bermudagrass hay production in the LSRB because of lower yield and forage CP. The only advantage of BL was greater forage P. We think that bermudagrass performance was less with BL because of less available N for plant uptake, probably a direct result of ammonia volatilization losses from the soil surface, which can be an environmental concern. Ammonia emissions into the atmosphere can contribute significant quantities of N to nearby bodies of water and lead to eutrophication (Luebs et al., 1973; Reddy et al., 1979; Meisinger and Jokela, 2000). Our forage performance data support the general N availability estimations

Table 6. Dry matter yield, forage N concentration, and forage N removal for bermudagrass harvested in July 2001 at Suwannee, following N fertilizer treatments (sources and levels) imposed on plots from July 1998 through August 2000. Soil total N is from the upper 7.6 cm of topsoil at the Gilchrist location sampled in May 2001.

N level†	N source‡	Yield§	Forage N	Forage N removal	Soil total N
kg ha^{-1}		Mg ha^{-1}	g kg^{-1}	kg ha^{-1}	
42	AN	1.1	9.5	11	460
84	AN	1.6	8.2	13	510
126	AN	2.3	7.6	17	535
168	AN	3.4	8.5	28	550
Polynomial effects for only AN¶		L**	NS	L** Q*	NS
84	BL	2.2	8.6	19	650
126	BL	3.0	9.3	28	690
84	ANBL	1.7	8.9	15	540
126	ANBL	2.5	8.3	21	580
LSD (0.05) for sources AN, BL, and ANBL comparison		0.4	0.7	4	120

*Significant at the 0.05 level.

**Significant at the 0.01 level.

†Level is the amount of N applied per growth period during 1998 (two growth periods), 1999 (four growth periods), and 2000 (three growth periods).

‡AN, sole N source ammonium nitrate; BL, sole N source broiler litter; ANBL, combination N source ammonium nitrate plus broiler litter with each source supplying 50% of N.

§No fertilizers were applied to bermudagrass plots after August 2000.

¶For AN only, linear (L) and/or quadratic (Q) effects are significant with increasing N level. NS, not significant.

for surface-applied, unincorporated BL, ranging from 50 to 70% during the application year (Mitchell and Donald, 1995; Evers, 1998; Gaskin et al., 2007). However, attempts to boost forage performance by applying greater amounts of broiler litter to the soil surface to account for reduced N availability likely will increase ammonia emissions. This action will also increase the amount of applied P, further escalating environmental problems associated with the low N:P ratio in broiler litter and P-saturated soils. Furthermore, excessive application of broiler litter can lead to nitrate N leaching (Liebhardt et al., 1979). A conservative approach to avoiding substantial N loss via nitrate leaching from bermudagrass hayfields in the LSRB, would be to not exceed an "available" N application of 126 kg ha^{-1} per growth period for surface-applied broiler litter. Assuming 60% N availability during the application season, the "equivalent" N level for broiler litter would be 210 kg ha^{-1}.

Forage Response to Apparent "Carryover" Nitrogen in 2001

At the Suwannee location, bermudagrass plots were harvested 19 July 2001 to measure effects associated with residual soil N following the previous two and a half growing seasons when N source-level treatments were imposed. During that period, about 27 and 41 Mg ha^{-1} of broiler litter were applied to BL plots for N applications of 84 and 126 kg ha^{-1} per growth period, respectively. For AN, yield and N removal increased with increasing N level, evidence that carryover N increased with increasing applied N (Table 6). Forage N concentration was variable, ranging narrowly from 7.6 to 9.5 g kg^{-1} (48–59 g kg^{-1} CP). Across common N levels, forage yield and N removal were greater for BL than AN by an average of 0.7 Mg ha^{-1} DM and 9 kg N ha^{-1}, respectively. Though differences in plant responses were minor, a greater amount of carryover N was probably present in BL plots in 2001. It should be noted that yield for AN applied at 168 kg N ha^{-1} was greater than that of BL at 126 kg N ha^{-1} (3.4 vs. 3.0 Mg ha^{-1}), while N removal in the harvested forage did not differ.

Analysis of the upper 7.6 cm of topsoil (sampled May 2001) at the Gilchrist site revealed that at common levels of applied N, there was a greater average amount of soil N in BL plots (670 kg N ha^{-1}) vs. AN plots (523 kg N ha^{-1}). Soil N was also greater for BL at 126 kg N ha^{-1} than AN at 168 kg N ha^{-1}. Differences were confined to the upper 7.6 cm of topsoil. Disparities were not detected among N source–level treatments in topsoil from the 7.6- to 15.2-cm depth (data not shown). These data indicate that a measurable amount of N from BL remained in the uppermost layer of topsoil in 2001. However, the apparent quantity of available N, based on forage yield and N removal at Suwannee, was almost inconsequential. The average difference in soil N (May 2001) between the lowest N level for AN (i.e., 42 kg N ha^{-1} and the lowest apparent carryover N) and the highest N level for BL (126 kg N ha^{-1} and the highest apparent carryover N) was 230 kg N ha^{-1}. Although this amount is substantial, its availability was apparently low, since the difference in forage N removal at the Suwannee location between the two N source-levels was only 17 kg N ha^{-1}. Assuming that another 17 kg N ha^{-1} would be available in the second half of the 2001 season, a total of 34 kg N ha^{-1} would be available for uptake during the entire growing season. At best, this total would amount to 9% of the applied N over the 2000 season, not accounting for carryover N from 1998 and 1999, which would reduce the estimate even more. Gordillo and Cabrera (1997) showed that net N mineralization rates decreased to very low levels 60 d after BL application. It is generally reported that 8 to 15% of the N from surface-applied broiler litter is available after the application year (Mitchell and Donald, 1995; Evers, 1998). Our results indicate that the amount of carryover N available for plant uptake following an application year would be at the low end of that range in the second season. Therefore, we think that the effect of carryover N from broiler litter on bermudagrass performance should be considered almost negligible, assuming amounts of N applied with BL are similar to those of the current study.

Broadleaf Weed and Bahiagrass Coverage Ratings in 2001

During the first half of 2001, new weed species were not observed at either site. Final broadleaf and bahiagrass area coverage ratings were made in July 2001 (Table 7). At Gilchrist, broadleaf weed coverage ratings of plots fertilized with BL were greater than or equal to those fertilized with AN at common levels of applied N. However, ratings for BL did not differ from AN applied at 42 kg N ha^{-1}. Similarly, bahiagrass ratings for BL at Suwannee, though not significantly different, tended to be greater than AN at common N levels. But the rating for AN at 42 kg N ha^{-1} did not differ from BL at 84 kg N ha^{-1} and was actually higher than BL applied at 126 kg N ha^{-1}. A possible explanation is that weed coverage was related to the amount of available N for plant uptake and consequently to the degree of aggressiveness of bermudagrass to suppress weed growth. This relationship was evident at both locations as weed ratings declined linearly with increasing N applications of AN (Table 7). Therefore, we attribute higher weed ratings in BL plots to the poor performance of the bermudagrass associated with lower amounts of N available for plant uptake. The slower growth of the bermudagrass allowed greater opportunity for weeds to emerge and grow. Gaskin et al. (2007) also reported a greater proportion of ground coverage occupied by annual grasses, broadleaf weeds, and bare ground in bermudagrass hayfields that had been fertilized with poultry litter at an N level of 194 kg ha^{-1} yr^{-1} during a 5-yr period, compared to those receiving ammonium nitrate at 224 kg N ha^{-1} yr^{-1}. They concluded that the increase in weeds was not due to weed seeds in the poultry litter but rather to the availability of nutrients throughout a longer period of time, which stimulated more weed seeds to germinate and compete well with the bermudagrass. Mitchell et al. (1993) combined sterile potting medium with broiler litter collected from 18 different broiler houses throughout Alabama. After 42 d of incubation, no plants emerged. It was concluded that broiler litter does not introduce weed seed into pastures.

Table 7. Average broadleaf weed (Gilchrist site) and bahiagrass (Suwannee site) ground coverage rating scores of bermudagrass plots in July 2001, following 2.5 yr (1998–2000) of fertilizer applications with different sources and levels of N.

N level†	N source‡	Weed score: Broadleaf§	Weed score: Bahiagrass¶
kg ha^{-1}			
42	AN	2.8ab	2.9a
84	AN	2.2b	2.3ab
126	AN	1.8bc	1.2cd
168	AN	1.2c	1.0d
Polynomial effects for only AN source#		L**	L**
84	BL	3.4a	2.7a
126	BL	1.8bc	1.8bc
84	ANBL	2.1b	2.7a
126	ANBL	2.0bc	1.5cd

**Significant at the 0.01 level.

†Level is the amount of N applied per growth period. There were two, four, and three growth periods in 1998, 1999, and 2000, respectively. No fertilizer was applied after August 2000.

‡AN, sole N source ammonium nitrate; BL, sole N source broiler litter; ANBL, combination N source ammonium nitrate plus broiler litter with each source supplying 50% of the N.

§Average broadleaf weed coverage rating score for the Gilchrist site with scale: 1 = almost no broadleaf weeds; 5 = most broadleaf weeds with about 15% ground coverage. Means within the column with the same lowercase letter are not different ($P > 0.05$).

¶Average bahiagrass coverage rating score for the Suwannee site with scale: 1 = almost no bahiagrass; 5 = most bahiagrass with about 20% ground coverage. Means within the column with the same lowercase letter are not different ($P > 0.05$).

#For only AN, linear (L) polynomial effect is significant with increasing N level.

SUMMARY AND CONCLUSIONS

For AN, the greatest impact of increasing fertilizer N levels was on bermudagrass yield and CP concentration. Dry matter yield and forage CP increased to the greatest N level. As fertilizer N level increased, forage P declined while IVDOM increased, but the magnitude of change was marginal for both forage components. Broiler litter was inferior to ammonium nitrate as an N source for bermudagrass production. Mean DM yield for BL ranged from 48 to 67% of the yield obtained from AN. Forage CP was generally lower for BL compared to AN. However, forage P was noticeably greater, which was attributable to the greater amounts of P accompanying the BL source of N. For BL, lower yield and CP probably were related to lower levels of available N for plant uptake, likely due to loss of N at the soil surface via ammonia volatilization. In addition, a portion of N in BL during the season of application probably was resistant to mineralization and not available for plant uptake. The quantity of apparent carryover N from BL applied in previous seasons (1998, 1999, and 2000), was measurable. However, the effect of carryover N on forage production was minor over the first half of the 2001 growing season.

Nitrate leaching patterns show that N movement out of the primary rooting zone was minimal for BL, eliminating leaching as a major avenue for N loss. Leaching patterns indicated that substantial fertilizer N moved below the primary rooting zone for AN applied at the highest N level. Nitrate that has leached below the primary rooting zone represents both a monetary loss of fertilizer N and a potential risk for groundwater contamination in the LSRB. A potential environmental impact of surface-applied BL would involve ammonia emissions at the soil surface and its impact on nearby surface waters.

For AN, weed ground coverage ratings in 2001 decreased as N level increased. It was concluded that bermudagrass had a greater ability to suppress weed growth at greater N levels. The greater weed coverage from BL applications was a result of less available N for plant uptake, causing the bermudagrass to be less competitive with weeds.

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