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RESEARCH ARTICLE

Broiler chicken litter application timing effect on Coastal bermudagrass in southeastern U.S.

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Abstract Presently, more than 85% of the broiler chicken (*Gallus gallus domesticus*) litter (BCL) is being applied to pasture lands year-round. This practice results in nutrient losses and potentially unfavorable environmental impacts particularly during the wet winter months. A field plot experiment was initiated in 2001 on a Ruston silt loam in Mize, MS to identify the proper BCL application timing that enhances BCL nutrient uptake by crops while minimizing undesirable nutrient buildup in soil. Seven treatments (BCL application timings) were employed on previously established "Coastal" hybrid bermudagrass [*Cynodon dactylon* (L.) Pers.] plots. For each treatment, the quantity of broiler chicken litter (a mixture of chicken manure plus bedding materials) needed for each plot was calculated based on the BCL total N content to provide 400 kg N ha^{-1} for top bermudagrass yield (18 Mg ha^{-1}) and applied either as a single, two-way split, or three-way split at different dates as follow: May; May/June; April/May/June; May/June/July; June/July/August; July/August/September; and August/September/October. Bermudagrass was harvested 5 times each year for dry matter (DM) and nutrient uptake determination. Significant differences in DM yield were observed in each year among application timings. The greatest DM yield was 18.6 Mg ha^{-1} for the single application in May and lowest at 15.0 Mg ha^{-1} for Aug/Sep/Oct application dates in 2001 and followed by the same trend in 2002. The N and P uptake by bermudagrass ranged from 270 to 381, and 53 to 63 kg ha^{-1} respectively, in 2001. Similar trend, but lower values for nutrient uptake were observed in 2002. Significant differences were observed among BCL application timings in regard to soil residual of total carbon (TC), total nitogen (TN), Mehlich 3 extracted P (M3-P), NO_3–N, Cu, and Fe elements at the end of the study. In general, summer and early fall BCL applications resulted in greater buildup of most of these elements. Based on the results of this study, there is a wide window (May–July) for BCL application timing on bermudagrass considering the criteria of producing high yield and low soil residual nutrient. However, the best BCL application timing should be in spring (late April–June) when minimum temperatures exceed those required (24–27°C) for bermudagrass growth.

Keywords Broiler litter · Poultry manure · Bermudagrass · Forage

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Introduction

Addition of animal manure to soil as fertilizer is not always environmentally beneficial. The disparity between the N and P ratio in manure (3:1) and crop requirements (8:1) has led to excess P loading of soil when manure application rates are N-based (Daniel et al. 1994; Sims 1995; Gilley et al. 2002). Manure and crop management practices appear to affect the nutrient status of soil by buildup, leaching, or surface runoff from soils (Sims et al. 1998). For example, incorporation of manure in contrast to broadcast application, manure application during dry soil conditions, and longer periods between applications may reduce nutrient leaching and runoff from soils (Geohring et al. 2001). Seasonal applications may impact nutrient losses, for example Sims et al. (1998) reported that fall applications of swine manure resulted in greater losses. Van Es et al. (2004) also reported the greatest loss of P from liquid manure for early fall application. However, Geohring et al. (2001) suggested that late summer and early fall applications of dairy manure resulted in lower P losses. These studies and many others indicate that management, soil properties, and crop factors greatly affect manure nutrient losses and potentially other environmental factors. However, with regard to broiler chicken litter (BCL) application timing on pasture and hay fields, little information exists for making sound recommendations on the proper timing of BCL application.

Nutrient removal in the harvest mass (estimated nutrient uptake) is calculated from plant biomass and nutrient concentration, but, both factors may vary due to management practices, weather conditions, and soil properties (McLaughlin et al. 2004, 2005). Bermudagrass (warm-season) is the predominant forage grass grown in the southeastern USA (Burton and Hanna 1995), and responds readily to increasing N rates from application of animal manure (Overman et al. 1993). For example, in North Carolina, Burns et al. (1985) reported that Coastal bermudagrass receiving 670 kg N ha^{-1} and 153 kg P ha^{-1} from swine effluent removed an average of 382 (57%) and 43 (28%) kg ha^{-1} $year^{-1}$ N and P, respectively. The bermudagrass harvesting for hay usually takes place in warm summer months, which also corresponds to maximum demand for nutrients. Therefore, annual forage dry matter production and nutrient uptake may be improved by litter application timing to provide required nutrients for maximum dry matter (DM) production. Ball et al. (1991) reported that the growth of bermudagrass in the summer months may be limited by daylength and temperature. On the other hand, BCL is being applied anytime during the year, depending on the producers' need to remove litter from the poultry house. If BCL is applied in early spring (mid March to late April), moisture is available for grass growth, but nutrients may be lost in runoff (Sharpley et al. 1994). If BCL is applied in the summer, temperature is more favorable for bermudagrass growth, but N may be lost due to NH_3 volatilization (Brinson et al. 1994). Ultimately, BCL application should be timed so that nutrient availability coincides with the optimum conditions for growth of the forages receiving litter to maximize yield, nutrient uptake, and thus minimize the potential loss of nutrients to the environment (Brink et al. 2002, 2004).

The majority of the BCL generated by the US poultry industry is land-applied year-round within short distances of the poultry production facilities on pasture and hay fields in order to provide plant nutrients or as a way of disposing it (Sistani et al. 2004). This practice may cause a significant buildup of nutrients and salts in soils, and may impact environmental quality particularly in the south-central and southeastern USA (Simrad et al. 1995). Currently, in many states, no regulations prohibit poultry producers from applying litter in rainy and wet months of the year, which potentially increases the chance of leaching and runoff of BCL nutrients. However, it is expected that state or federal regulations will prohibit year-round poultry litter application. Thus, site-specific management practices and reliable information regarding BCL application timing that minimize negative environmental impact and maximize utilization of litter nutrients by crops are warranted. The objective of this research was to determine the effects of BCL application timing on yield, nutrient uptake, and changes in soil nutrient status to ascertain the optimum timing for minimizing soil nutrient build-up.

Materials and methods

The study was conducted in Mize, MS (31.8° N, 89.6° W) on a Ruston soil (fine-loamy, siliceous, thermic Typic Paleudults). Initial soil samples from 0 to 10 and 10 to 20 cm depths were collected from plots (2 × 6 m, separated by 1-m alleys) previously established with 'Coastal' hybrid bermudagrass cultivar. The study area was part of typical hay and pasture fields in the region to which broiler litter has been applied for many years. Broiler litter was hand-applied at the rate to deliver 400 kg N ha^{-1} per year, which was the N requirement of bermudagrass to meet the target maximum yield of 18 Mg ha^{-1}. The quantity of the broiler litter needed at each application was calculated based on the total broiler litter N content (Table 1) and the size of the experimental plots (12 m^2). Treatments consisted of seven litter application dates ranging from early spring to early fall as follows: a single application in May; split applications in May and June (1/2 the amount of needed litter in each month); three-way split applications in April/May/June; May/June/July; June/July/August; July/August/September; and August/September/October (1/3 the amount of needed litter in each month). The required amount of litter (calculated based on litter N content) for each application date was applied in such a way that all the plots received the same amount of N by the end of the year regardless of single, two-way, or three-way splits. Broiler litter was obtained from a nearby broiler house (the same house during the life of the experiment) at each application date. Subsamples of broiler litter were obtained for nutrient determination prior to each application. The N, P, and K concentrations of litter did not change significantly at each collection time, because broiler litter was collected from the same house under the same management (e.g. the same integrator and feedstuff) (Table 1). Also, to avoid significant changes in the litter nutrient composition, the fresh surface crusting manure (cake) of the bedding materials was removed first, then litter was collected from deeper and more stable parts of the bedding materials in the house.

Forage yield was determined by cutting a 1 × 6-m swath at a 5-cm stubble height through the center of each plot with a sickle-bar mower every 4–6 weeks. In both years, the first harvest was in late May to early June, while the last harvest was in late October. Subsamples were taken and dried at 65°C for 48 h for forage dry matter (DM) determination. Background soil samples were collected in 2001 prior to the first litter application (Table 2) then followed by a yearly sampling during the two complete growing seasons in 2001 and 2002 to determine the soil nutrient status under each broiler litter application timing. Soil samples were collected during late October to late November after bermudagrass started the dormancy.

Table 1 Broiler chicken litter analysis (dry weight basis) for each application timing

Date	Moisture (%)	pH	N (g kg^{-1})	C (g kg^{-1})	P (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	K (g kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
April-01	22.4	7.3	31.7	326	20.9	30.4	5.66	27.5	505	882	612	426
May-01	20.0	7.1	31.1	378	20.2	30.0	5.84	26.4	515	896	635	455
June-01	19.8	7.5	30.7	371	21.0	29.7	6.90	26.9	525	852	599	400
July-01	18.8	7.6	31.0	326	19.8	30.3	5.90	25.8	503	887	601	399
August-01	18.9	7.4	29.2	329	20.4	30.6	6.70	26.6	507	901	599	389
September-01	22.2	7.6	29.8	306	20.6	29.6	6.30	25.4	498	899	588	401
October-01	22.2	7.6	29.7	369	19.9	30.2	6.80	26.2	497	846	596	422
April-02	21.3	7.3	29.9	344	19.8	30.7	6.40	27.1	499	891	598	445
May-02	22.2	7.4	29.8	291	20.2	29.8	6.00	26.8	514	903	612	452
June-02	19.6	7.2	31.1	361	20.7	29.1	7.10	26.6	516	877	594	457
July-02	21.6	7.3	30.8	321	20.6	30.1	6.27	25.3	526	896	568	460
August-02	20.5	7.3	30.2	333	19.7	29.8	6.40	27.0	524	875	586	465
September-02	21.1	7.6	29.6	345	19.8	29.9	5.84	26.8	516	849	596	455
October-02	22.5	7.7	31.1	299	19.8	30.1	6.44	26.7	501	812	599	444
Average	20.9	7.4	30.4	336	20.2	30.0	6.32	26.5	510	876	599	434

Table 2 Initial selected soil chemical properties

Soil depth (Cm)	pH	TC ($g\ kg^{-1}$)	N ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	Ca ($g\ kg^{-1}$)	Mg ($g\ kg^{-1}$)	P ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)
0–10	5.6	13.8	1.09	0.13	0.75	0.10	303	16.5	354	346	17.8
10–20	5.9	6.14	0.41	0.08	0.45	0.08	174	3.41	209	265	1.2

Mehlich-3 extractant was used to extract soil for metal determination

Chemical analyses

The following chemical analyses were performed on bermudagrass DM, BCL, or soil samples. Soil pH was measured in a 1:1 soil:water ratio using 10 g soil. Soil, plant, and litter total N (TN) and total carbon (TC) were measured by dry combustion using CE Elantech (Lakewood, NJ) CN analyzer. Soil samples (2 g) were extracted with 0.01 M KCl (1:10 soil:KCl ratio) (Mulvaney 1996) and analyzed for nitrate (NO_3–N) and ammonium (NH_4–N) using a Dionex-500 ion chromatograph (Sunnyvale, CA). Soil samples were extracted with Mehlich-3 soil extractant (Mehlich 1984), 1:10 soil:extractant using 2 g soil, shaken for 30 min, and filtered through Whatman Fisher brand filter paper (2V) for the determination of P and metals using a Thermo Jarrell-Ash inductively coupled plasma spectrophotometer (ICP), (Franklin, MA). Soil total P (TP) was determined by digesting 0.50 g of air-dried soil using sulfuric acid, hydrogen peroxide, and hydrofluoric acid (Kuo 1996) followed by the determination of P using the ICP. Approximately 0.8 g plant tissue or broiler litter was ashed in a muffle furnace (Thermolyne Corporation 30400, Dubuque, Iowa) at 500°C for 4 h. Ash was dissolved first in 1.0 ml of 6 N HCl for one h, followed by 50 ml of a double acid solution of 0.025 N H_2SO_4 and 0.05 N HCl, and the mixture was allowed to stand for another hour prior to filtration (Southern Cooperative Series 1983). The ashed samples were used for the following analyses: TP, K, Ca, Mg, Cu, Fe, Mn, and Zn using the ICP.

The study was a randomized complete block design with 7 treatments (BCL application dates) and 4 replicate blocks conducted at the same site for 2 years. Data were analyzed using the PROC GLM procedure of SAS (1999). Dry matter yield and nutrient uptake were analyzed separately by year because year, and year × treatment interactions were significant ($P < 0.01$). Mean comparisons were done by year using Fisher's protected LSD ($P < 0.05$). Analysis of soil chemical data was performed using values from 0 to 10 cm depths.

Results and discussion

Dry matter and nutrient uptake

Figure 1 shows the rainfall record for 2001 and 2002 for Mize, MS. Normally bermudagrass growth and DM production directly relates to the quantity and the distribution of the rainfall during spring and summer when bermudagrass growth is at its peak and demand for water is high. In 2002, herbage DM yield was limited by rainfall followed by the lack of optimum soil moisture particularly in May, June, and August compared to the 2001 growing season. This was observed by lower DM yield in late summer harvests in 2002. In 2001, litter application dates in May, May/June, and Apr/May/Jun produced significantly greater annual DM yield of18.6, 18.2, and 17.7 Mg ha^{-1} respectively, than other BCL application dates (Fig. 2). The application dates of May/Jun/Jul and Jun/Jul/Aug were not significantly different, but significantly different than Jul/Aug/Sep and Aug/Sep/Oct application dates. In 2002, for all BCL application dates, DM yield was much lower than in 2001 because of low rainfall in May, June, and July (Fig. 1). However, similar trend was observed in regard to DM yield response to BCL application timings. No significant differences in DM yield was observed among May, May/Jun, Apr/May/Jun application dates. The May/Jun/Jul application date produced relatively much lower DM yield in 2001 than the same date in 2002. In both years, Jul/Aug/Sep and Aug/Sep/Oct dates had the lowest DM yield than other litter application dates (Fig. 2). Evers (1998) found BCL application on Coastal bermudagrass in late spring increased forage yield 10–20%

over a split application in late spring and mid summer. He explained the increase was due to greater soil moisture in early spring than in late summer. Brink et al. (2002) also reported that split application of BCL on bermudagrass had no beneficial effect on yield or N and P uptake compared to a single application, unless, the single application is made very early in spring. They also reported that increasing broiler litter rate for May application did not increase individual harvest yield, however, the rate increase for April litter application date increased DM yield for the following harvests until September.

Annual nutrient uptake was calculated as the product of forage DM yield and forage nutrient concentration at each harvest and summed over all harvests. Significant differences among the litter application dates were observed for N and P uptake. Similar to annual DM yield, N and P uptake was greatest in May and May/Jun application dates in 2001. All the three-way splits application dates had similar N and P uptakes except for N uptake which was the lowest in Aug/Sep/Oct date. In 2001, N uptake ranged from 270 to 400 kg ha^{-1}, while the corresponding range for 2002 was 250–277 kg ha^{-1} (Fig. 3). The N uptake in 2002 was the same for May, May/Jun, and Apr/May/Jun litter application dates. However, the N uptake in May/Jun/Jul application date was unexpectedly lower than Aug/Sep/Oct date (Fig. 3). The annual P uptake ranged from 52.8 to 63.4 kg ha^{-1} in 2001, and 28.0 to 39.0 kg ha^{-1} in 2002. The P uptake in 2001, a favorable rainfall year, was greater than those reported by Sistani et al. (2004) for Coastal bermudagrass (46 kg ha^{-1}) and the P uptake from swine effluent (50 kg ha^{-1}) reported by Brink et al. (2003). The K uptake by bermudagrass followed the same trend as N and P uptake. However, there is no environmental concern over the accumulation of K in soil from litter application.

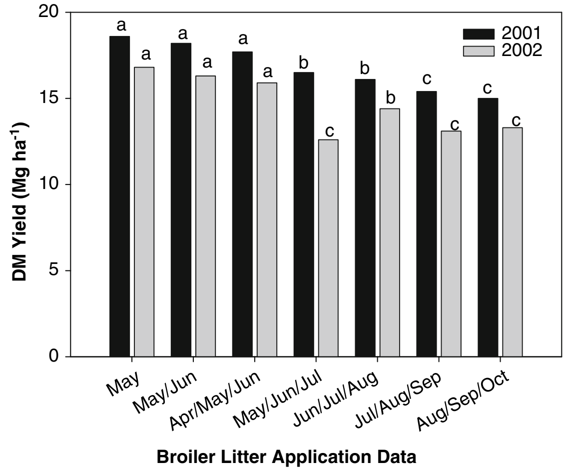

Fig. 2 Annual dry matter yield (DM) of Coastal bermudagrass as influenced by different broiler litter application dates. For each year, bars with the same letters are not significantly different (LSD 0.05)

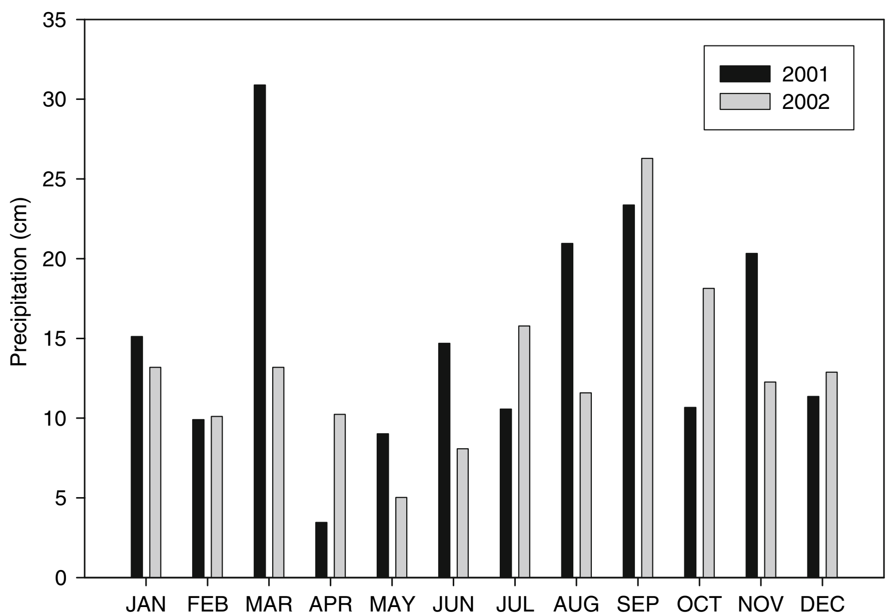

Fig. 1 Total monthly precipitation during the course of the experiment

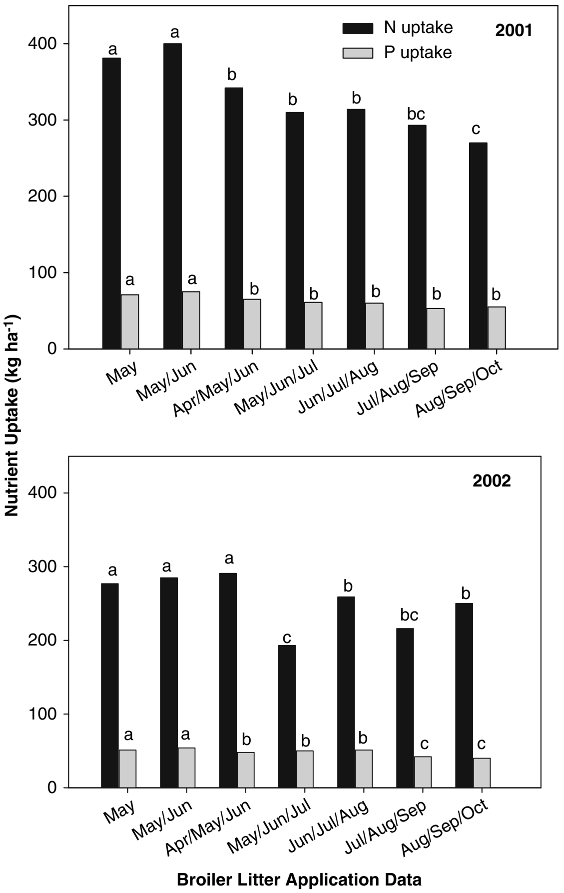

Fig. 3 N and P uptake by Coastal bermudagrass as influenced by different broiler litter application dates. In each year and for each nutrient, bars with the same letters are not significantly different (LSD 0.05)

Table 3 shows the mean nutrient concentration of bermudagrass DM for N, P, K, Cu, Fe, Mn, and Zn. The bermudagrass herbage N concentration in May and in May/Jun was significantly greater than other application dates. The herbage N and P concentrations were similar in most of the three-way splits BCL application dates. In general, the spring BCL application dates produced herbage with greater N, P, and K concentration than summer and early fall application dates. This may be due to a favorable soil moisture and temperature condition that promote greater mineralization of BCL nutrients. There was great variability among micronutrient concentrations in bermudagrass herbage at different BCL application dates. No specific trend was observed in regard to Cu, Fe, Mn, and Zn herbage concentrations at different BCL application timings in both years (Table 3). For example significant differences were observed in herbage Cu and Fe concentration in 2001, while no differences were observed for the same metals in 2002 for different BCL application dates.

Soil nutrient status

From a nutrient management stand point, a proper BCL application date should result in a maximum BCL nutrient uptake by crops, and also in a minimum nutrient buildup (residual) in soil, particularly for elements such as P and heavy metals. Soil nutrient levels under each BCL application date at the end of the study are presented in Table 4. Since interactions among the BCL application dates and soil sampling dates were not significant, averages of three soil sampling dates are reported. Broiler chicken litter application date did not influence soil pH, however there was a decrease in soil pH for all BCL application dates compared to initial soil pH (Table 2). Significant differences for total carbon (TC) were observed among BCL application dates with greater accumulation occurring for Jul/Aug/Sep and Aug/Sep/Oct BCL application dates (Table 4). Compared to initial soil TC content of 13.8 g C kg^{-1}, all the BCL application dates had a greater TC at the end of the experiment with Jul/Aug/Sep application date having the greatest, 17.7 g C kg^{-1}. Greater soil C accumulation in summer compared to spring application dates may be due to higher soil temperature and lower soil moisture that may have inhibited soil organic matter decomposition, which has resulted in lower C losses. Soil N content followed the same trend as C in which plots that received BCL in three-way split application in Jul/Aug/Sep and Aug/Sep/Oct had significantly greater N content in the 0–10 cm soil depth.

It has often been reported that because of the low N:P ratio in litter relative to plant uptake, P accumulation will occur if BCL application rate is based on the crops N requirement. In this study, Mehlich 3 extracted soil P (M3-P), a measure of P availability to the crop at the end of the experiment, was greater than initial M3-P (Table 2) for four BCL application dates occurring mainly in the early summer and early fall (Table 4). The soil M3-P for these application dates, Jun/Jul/Aug, Jul/Aug/Sep, and Aug/Sep/Oct increased from 303 mg kg^{-1} (initial) to 352, 368, and

Table 3 Coastal bermudagrass herbage nutrient concentrations (average of five harvests) as influenced by different broiler chicken litter application dates in 2001 and 2002

Litter application date	N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
2001							
May	20.5a	3.5a	21.0a	6.67a	54b	113bc	45b
May/Jun	21.0a	3.6a	20.5ab	7.11a	58ab	131a	46b
Apr/May/Jun	19.8ab	3.3b	19.5b	7.19a	65a	117ab	50ab
May/Jun/Jul	18.8bc	3.2b	19.7ab	7.08a	56b	119ab	54a
Jun/Jul/Aug	19.5b	3.2b	20.2ab	5.67b	61ab	107bc	48b
Jul/Aug/Sep	19.0bc	3.1b	19.3b	7.06a	57ab	103c	50ab
Aug/Sep/Oct	18.0c	3.2b	17.5c	6.58a	61ab	106bc	50ab
LSD †	1.3	0.3	1.4	1.50	9	16	5.7
2002							
May	18.5a	2.9ab	16.6	7.41	112	96a	50b
May/Jun	17.5ab	3.1a	17.2	6.73	89	91ab	49b
Apr/May/Jun	17.5ab	2.7b	16.4	7.19	106	88ab	52b
May/Jun/Jul	15.3c	2.7b	16.2	7.27	111	91ab	57a
Jun/Jul/Aug	16.8b	2.8b	17.1	6.73	107	84bc	58a
Jul/Aug/Sep	16.5b	2.8b	17.1	6.80	108	76c	58a
Aug/Sep/Oct	16.0c	2.9ab	16.0	6.43	91	89ab	61a
LSD	1.2	0.2	NS	NS	NS	8.5	4.9

† Values within each year and column followed by the same letter are not significantly different from each other according to the Fisher's LSD 0.05 level. NS = not significant

344 mg kg^{-1}, respectively (Table 4). Since BCL was applied based on N requirement of the bermudagrass, more P was applied than the actual crop need. Therefore, the increase in soil P is attributed to over application of P by broiler chicken litter.

There were slight decreases in M3-P for May, Apr/May/Jun, and May/June/July BCL application dates compared to initial soil M3-P level. Significant differences were also observed among BCL application dates with regard to soil concentrations of Cu and Fe determined at the end of the experiment. In general, the residual buildup of most of these elements was greater for summer and early fall litter applications because of less uptake. Except for Fe and Mn, all other soil nutrient concentrations increased at the end of the study compared to initial soil concentration of these elements (Tables 2, 4).

Implication and conclusion

In many states of the United States, swine effluent application timing is regulated and limited to spring and summer months. In contrast, poultry litter is being surface land applied year-round. It is expected that poultry litter including BCL application during the winter months or rainy months will be prohibited. In this study, we attempted to identify proper date or dates for BCL application that maximizes nutrient uptake by crops and minimizes nutrient buildup in soil. Broiler chicken litter application timing influenced Coastal bermudagrass DM yield and nutrient uptake. In general, single, split, and three-way split BCL applications in spring and early summer produced greater DM yield and nutrient uptake than other BCL application dates. The residual buildup of C, which is a beneficial impact, and P, Cu, and Zn buildup, potentially negative impacts, were observed with all BCL application timings. However, soil buildup for most of the nutrients was lower in spring than summer and early fall applications. Our results indicate that BCL may be applied to bermudagrass as soon as the optimum temperature (24–27°C; Beard 1973) requirement for growth is reached in order to maximize nutrient uptake. However, late summer and early fall BCL applications may benefit a second

Table 4 Soil surface (0–10 cm) pH, total carbon (TC), total nitrogen (TN), Mehlich-3 (M3) extracted nutrient concentrations influenced by broiler chicken litter application dates, averaged across three sampling dates

Litter application date	pH	TC ($g\ kg^{-1}$)	TN ($g\ kg^{-1}$)	Ca ($g\ kg^{-1}$)	Mg ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	P ($mg\ kg^{-1}$)	NO^3–N ($mg\ kg^{-1}$)	NH_4–N ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)
May	5.3	15.2c	1.28c	0.71	0.11	0.14	291b	37c	14.6	12.7c	158a	164	52
May/Jun	5.4	16.1bc	1.37bc	0.74	0.11	0.15	311b	37c	14.0	13.5bc	158a	164	56
Apr/May/Jun	5.3	15.4c	1.30c	0.69	0.10	0.12	295b	40c	14.2	12.6c	144c	163	53
May/Jun/Jul	5.3	15.6bc	1.31c	0.73	0.10	0.13	297b	41c	15.2	12.2c	150bc	162	53
Jun/Jul/Aug	5.3	16.0bc	1.37bc	0.80	0.12	0.18	352a	68ab	12.2	15.5ab	148bc	167	57
Jul/Aug/Sep	5.4	17.7a	1.60a	0.88	0.13	0.25	368a	80a	15.5	16.2a	156ab	161	56
Aug/Sep/Oct	5.3	17.0a	1.47ab	0.83	0.12	0.18	344a	61b	14.9	15.4ab	151bc	163	55
LSD †	NS	1.4	0.15	NS	NS	NS	30	14	NS	2.2	9	NS	NS

† In each column, values followed by the same letter are not significantly different from each other according to the Fisher's LSD 0.05 level. NS = not significant

crop, for example, overseeding bermudagrass with a winter annual such as ryegrass (*Lolium multiflorum* Lam.), which is a common practice in southeastern U.S. The application dates selected for this study did not impact P uptake compared to N uptake, possibly because initial soil P levels were high or because bermudagrass requirements for P were relatively low compared with the quantity applied in the BCL (Brink et al. 2002; Pant et al. 2004; Read et al. 2006).

The practical significance of our findings is that selection of litter application timing as it relates to nutrient management options greatly impacts the quality of the potential surface runoff water exiting fields (Sauer et al. 2000; Pote et al. 2003). For example, a single application in May was as good or better than split or three-way split applications with regard to DM yield production or nutrient accumulation in soil, however, split applications may have lessened the BCL nutrient transport in runoff because less BCL is applied to soil surface at one time.

References

Ball DM, Hoveland CS, Lacefield GD (1991) Southern forages. Potash and Phosphate Inst. and Foundation for Agron. Res., Norcross

Beard JB (1973) Turfgrass: science and culture. Prentice Hall, Englewood Cliffs

Brink GE, Rowe DE, Sistani KR (2002) Broiler litter application effects on yield and nutrient uptake of 'Alicia' Bermudagrass. Agron J 94:911–916

Brink GE, Rowe DE, Sistani KR, Adeli A (2003) Bermudagrass cultivar response to swine effluent application. Agron J 95:597–601

Brink GE, Sistani KR, Rowe DE (2004) Nutrient uptake of hybrid and common bermudagrass fertilized with broiler litter. Agron J 96:1509–1515

Brinson SE, Cabrera ML, Tyson SC (1994) Ammonia volatilization from surface-applied fresh and composted poultry litter. Plant Soil 167:213–218

Burns JC, Westernman PW, King LD, Cummings GA, Overcash MR, Goode L (1985) Swine lagoon effluent applied to coastal bermudagrass: I. Forage yield, quality, and Element Removal. J Environ Qual 14:9–14

Burton GW, Hanna WW (1995) Bermudagrass. In Barnes RF et al (eds) Forages: an introduction to grassland agriculture, vol 1. Iowa State University Press, Ames, pp 421–430

Daniel TC, Sharpley A, Edwards DR, Wedepohl R, Lemunyon JL (1994) Minimizing surface water eutrophication from agriculture by phosphorus management. J Soil Water Conserv 49:30–38

Evers GW (1998) Comparison of broiler poultry litter and commercial fertilizer for coastal bermudagrass production in the Southeastern U.S J Sust Agric 12:55–77

Geohring LD, McHugh OV, Walter MT, Steenhuis TS, Akhtar MS, Walter MF (2001) Phosphorus transport into subsurface drains by macropores after manure applications: implication for best manure management practices. Soil Sci 166:896–909

Gilley JE, LM Risse, Eghball B (2002) Runoff and soil loss as affected by the application of manure. Trans ASAE 43:1583–1588

Kuo S (1996) Phosphorus. In: Bigham JM (ed) Methods of soil analysis, Part 3, Agronomy No. 5. Soil Science Society of America, Inc. ASA, Madison, pp 869–874

McLaughlin MR, Fairbrother TE, Rowe DE (2004) Nutrient uptake by warm-season perennial grasses in a swine effluent spray field. Agron J 96:484–493

McLaughlin MR, Sistani KR, Fairbrother TE, Rowe DE (2005) Overseeding common bermudagrass with cool-season annuals to Increase yield and nitrogen and phosphorus uptake in a hay field fertilized with swine effluent. Agron J 97:487–493

Mehlich A (1984) Mehlich 3 soil test extractant. Commun Soil Sci Plant Anal 15:1409–1416

Mulvaney RL (1996) Nitrogen-inorganic forms. In Bigham JM (ed) Methods of soil analysis, Part 3, Agronomy No. 5. Soil Science Society of America, Inc. ASA, Madison, pp 1123–1131

Overman AR, Sanderson MA, Jones RM (1993) Logistic response of bermudagrass and bunchgrass cultivars to applied nitrogen. Agron J 85:541–545

Pant HK, Adjei MB, Scholberg JMS, Chambliss CG, Rechcigl JE (2004) Forage production and phosphorus phytoremediation in manure-impacted soils. Agron J 96:1780–1786

Pote DH, Kingery WL, Aiken GE, Han FX, Moore PA Jr, Buddington K (2003) Water-quality effects of incorporating poultry litter into perennial grassland soils. J Environ Qual 32:2392–2398

Read JJ, Brink GE, Oldham JL, Kingery WL, Sistani KR (2006) Effects of broiler litter and nitrogen fertilization on uptake of major nutrients by coastal bermudagrass. Agron J 98:1065–1072

Sauer TJ, Daniel TC, Nichols DJ, West CP, Moore PA Jr, Wheeler GL (2000) Runoff water quality from poultry litter-treated pasture and forest sites. J Environ Qual 29:515–521

SAS Institute (1999) SAS/STAT user's guide. Version 8. SAS Institute, Cary

Sharpley AN, Chapra SC, Wedepohl R, Sims JT, Daniel TC, Reddy KR (1994) Managing agricultural phosphorus for protection of surface water: issues and options. J Environ Qual 23:437–451

Simrad RR, Cluis D, Gangbazo G, Beauchemin S (1995) Phosphorus status of forest and agricultural soils from a watershed of high animal density. J Environ Qual 24:1010–1017

Sims JT (1995) Characteristics of animal waste and waste-amended soils: an overview of the agricultural and environmental issues. In: Steele K (ed) Animal waste and the land-water interface. CRC Press, Boca Raton, pp 1–14

Sims JT, Simrad RR, Joern BC (1998) Phosphorus loss in agricultural drainage: historical perspective and current research. J Environ Qual 27:277–293

Sistani KR, Brink GE, Adeli A, Tewolde H, Rowe DE (2004) Year-round soil nutrient dynamics from broiler litter application to three bermudagrass cultivars. Agron J 96:525–530

Southern Cooperative Series (1983) Reference soil test methods for the southern region of the United States. Southern cooperative series, Bulletin No. 289. Georgia Agric. Exp. Stn., Athens

Van Es HM, Schindelbeck RR, Jokela WE (2004) Effects of manure application timing, crop, and soil type on phosphorus leaching. J Environ Qual 33:1070–1080