PRODUCTIVITY AND NUTRITIVE QUALITY OF JOHNSONGRASS AS INFLUENCED BY INTERSEEDED LADINO CLOVER AND FERTILIZATION WITH COMMERCIAL FERTILIZER OR BROILER LITTER

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# PRODUCTIVITY AND NUTRITIVE QUALITY OF JOHNSONGRASS AS INFLUENCED BY INTERSEEDED LADINO CLOVER AND FERTILIZATION WITH COMMERCIAL FERTILIZER OR BROILER LITTER

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VITA

Sandra Leanne Dillard, daughter of William and Sandra Dillard, was born May 21, 1985. Leanne grew up on a small poultry farm in Calhoun, Georgia. In 2003, she graduated from Calhoun High School receiving an International Baccalaureate Diploma. In the fall of 2003, she entered the University of Alabama at Birmingham in Birmingham, Alabama. In May of 2007, she graduated with a Bachelor of Science degree in Biology and a minor in Chemistry. Leanne began her graduate studies at Auburn University in May of 2007 under the co-direction of Drs. Russell Muntifering and Frank Owsley. While in the Animal Sciences Graduate Program, Leanne focused on Ruminant Nutrition, with special emphasis on forage quality and environmental stewardship. Prior to entering graduate school, Leanne was married to Hassan Elrhazouani on March 15, 2007.

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Johnsongrass (*Sorghum halepense*) is a warm-season perennial forage grown throughout the southeastern US. It was a very popular forage for cattle grazing during the early 20th Century; however, it currently is not utilized widely for grazing, but instead managed primarily as a noxious weed in row crops. Previous research has reported Johnsongrass to be a high-producing, medium-quality forage that can be grazed or used as a hay crop.

Over the last several decades, the poultry industry has expanded greatly in Alabama, especially in the Sand Mountain region. Broiler litter is an excellent organic fertilizer because of its low moisture content and high organic matter and nutrient content. However, after many years of repeated land application, high concentrations of some nutrients may accumulate in soil and become a potential liability to environmental quality, animal welfare and human health. Therefore, locating alternative areas in the state for land-application of broiler litter is warranted, and the Black Belt region of Alabama is of special interest in this regard because of its soils that are often of low fertility and historically have not been amended with broiler litter.

The current experiment utilized twenty-four 18-$m^2$ forage plots seeded with either Johnsongrass or a Johnsongrass-clover mixture. Three fertilizer source treatments were utilized, including commercial fertilizer (CF; ammonium nitrate and diammonium phosphate mixture), non-compacted broiler litter (BL-N) and compacted broiler litter (BL-C). Both broiler-litter treatments were applied on the basis of soil-test P and supplemented with ammonium nitrate to meet crop N requirement. Plots were harvested 2 times per year over the course of a 2-year experiment. Yield and forage quality data were analyzed using mixed-model procedures in which year was treated as a random effect and harvest as a repeated measure.

Results of this study indicate that DM yield and foliar concentrations of CP, NDF, ADF, lignin, Ca, P, Mg, Al, Cu and Fe were not affected by fertilizer-source treatments. However, hemicellulose and Zn concentrations were 8% lower ($P = 0.0526$) in forages fertilized with CF than broiler-litter treatments. Johnsongrass-clover contained 6% more CP ($P = 0.0753$) and 6% more hemicellulose ($P = 0.0854$) than Johnsongrass. Compacted broiler litter supported forage productivity and nutritive quality similar to those of forage fertilized with BL-N. Broiler litter applied on the basis of soil-test P and supplemented with ammonium nitrate was comparable to CF for supporting productivity and nutritive quality of Johnsongrass and Johnsongrass-clover forages grown on Black Belt soils.

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# I. LITERATURE REVIEW

## JOHNSONGRASS

### *Background*

Johnsongrass, *Sorghum halepense*, is a non-native plant species indigenous to the Mediterranean Region; however, its specific origin is much debated. It was introduced in South Carolina in 1835 and quickly gained popularity as a pasture forage throughout the Southeast. It was named after Colonel William Johnson of Marion Junction, Alabama, who is credited with its promotion as a well adapted sub-tropical forage (Beal, 1887). Throughout the late $19^{th}$ Century and into the early $20^{th}$ Century, Johnsongrass was used widely as mainly a hay crop in the Southeast. However, by the mid-1950s, Johnsongrass was recommended by only four Southern states as a useful forage crop due to its undesirable weedy characteristics (King, 1950). In 1998, only 28,147 ha (only 2.1% of Alabama's crop acreage) were planted with Johnsongrass (Alabama Agriculture Statistics Service, 1998).

### *Plant Characteristics*

Johnsongrass is a perennial, warm-season, $C_4$ grass that can grow up to 2 m tall. Its optimum temperature for growth is 30º C; however, it can survive in temperatures ranging from 13 to 50º C (Hull, 1970; Warwick and Black, 1983). Johnsongrass prefers slightly acidic soils, ranging from pH 5 to 7.5, and it also prefers clay soils because they have a higher water-holding capacity (Newman, 1993; Ball et al., 2007). For this reason, Johnsongrass production is normally limited to mesic sites with high moisture content (Newman, 1993). However, Johnsongrass is also drought tolerant, which allows it to survive the dry summer months of the southeastern US. The plant tissues produce an epicuticular wax on the leaves that reduces water vapor loss during respiration (McWhorter, 1993). This trait, coupled with its $C_4$ plant respiration, allows Johnsongrass to survive extended periods of drought that are common in the Southeastern climate. The production of the epicuticular wax increases during stress from drought conditions, further reducing its susceptibility to drought death (McWhorter, 1993). Johnsongrass is normally not considered to be cold-tolerant; however, some cold-tolerant ecotypes have evolved in the northern US and southern Canada (Warwick and Black, 1983). With this adaptation, Johnsongrass is currently found in all US states except Minnesota and Maine (USDA, 2009).

In addition to its drought tolerance, Johnsongrass has also been shown to be tolerant to high soil salinity. Sinha et al. (1986) reported that Johnsongrass can withstand high soil salt concentrations without many adverse effects as long as adequate water is provided. Increasing soil salinity from 0.5 to 10.0 ds/m decreased total plant biomass by 25.3%. However, increasing soil salinity significantly increased N, P, K, Ca, and Mg concentrations in plant tissues.

Currently, several states have included Johnsongrass on their invasive weed list, meaning that the plant cannot be deliberately planted within the state. Johnsongrass has evolved into an invasive weed, mainly because of its reproductive characteristics that include the capability to produce rhizomes. Warwick and Black (1983) reported that Johnsongrass could produce between 60 to 90 m of underground rhizomes per plant per growing season in Mississippi, which means that each plant can produce multiple shoots that can be up to 90 m away from the main shoot. In addition to the massive amounts of rhizomes, each Johnsongrass seed head can contain thousands of very small seeds that are easily spread by wind or rain. Johnsongrass is considered a pioneer species and, because of its extensive seed and rhizome production, it can quickly establish itself, which is another reason for its invasive weed classification (Newman, 1993).

Johnsongrass is normally managed for hay production, and it can easily be grazed with proper management. Rotational grazing of Johnsongrass is usually recommended to maintain good stands (Ball et al., 2007). Normally, a seeding rate of 22 to 34 kg/ha is recommended to establish a Johnsongrass forage stand. Seeds are normally planted 1.3 to 2.5 cm below the soil surface. At this rate and depth, seedling vigor is considered good (Woodruff et al., 2007).

When used as a forage crop, two particularly noteworthy plant toxicities are associated with Johnsongrass. Prussic acid poisoning of cattle ingesting Johnsongrass can occur if certain environmental conditions prevail. During times of drought or after a frost, concentrations of hydrogen cyanide may increase to toxic levels; however, these do not increase over time, and eventually the concentration in the forage will return to normal levels. Plant tissues of Johnsongrass can also contain toxic concentrations of nitrates. This toxicity can occur in forage that has experienced a drought or stunted plant growth following cool, cloudy weather. The major difference between these two toxicities is that nitrate concentrations do not decrease in the plant tissues after harvesting, so Johnsongrass hay may contain toxic concentrations many months later (Ball et al., 2007).

*Nutritive Quality and Crop Yield*

Johnsongrass is considered to be moderately palatable and of medium forage quality compared with other commonly planted warm-season forages (Newman, 1993). Fraps and Fridge (1940) reported that the nutritive quality of Johnsongrass changed with maturity of the plant. When the plant was young and still in its vegetative stage, it had a CP concentration of 9.2%, an ether extract (crude fat) concentration of 2.3%, and a crude fiber (CF) concentration of 28.5%. As the plant tissues matured, the CP decreased to 5.4%, the ether extract to 1.4%, and the CF increased to 32.4%. These data indicate that nutritive quality of Johnsongrass decreased as tissues matured. This pattern is similar to that of other warm-season forages in that most plant tissues increase in fiber concentration and decrease in CP concentration with maturity, both of which decrease the overall forage nutritive quality.

Johnsongrass can also produce medium-quality hay when cut at the boot stage, before the plant is allowed to produce seed. Unlike $C_3$ forages that store carbohydrates largely in the form of fructosans, Johnsongrass stores carbohydrates primarily as sucrose and starch (Newman, 1993). Grimes (1930) reported that Johnsongrass hay was similar to timothy hay in nutritive quality when fed with oat (*Avena sativa*) grain for 3 mo to draft horses and work mules. During the 3-mo trial, the animals were placed under a moderate or a heavy work load in a mine. After 3 mo, both species had maintained their body weight under moderate workloads; however, both species lost weight under heavy workloads when fed Johnsongrass and Timothy hay. The animals receiving Timothy hay lost an average of 4.9 kg during the experiment, whereas the animals receiving Johnsongrass hay lost an average of 9.9 kg. The investigators also determined the concentration of digestible nutrients in each forage. Johnsongrass hay averaged 2.9% CP, 45% total carbohydrates, and 1.0% crude fat. By comparison, Timothy hay averaged 88.4% DM, 3.0% CP, 42.8% total carbohydrates, and 1.2% crude fat. In addition to its moderate nutritive quality, Johnsongrass pastures can routinely produce between 4,500 and 11,200 kg of hay/ha (Ball et al., 2007).

Johnsongrass is best managed for hay production, but can be grazed if carefully managed. Ball et al. (2007) suggest use of management practices such as rotational grazing with a rest period, or continuous grazing at a low stocking rate and leaving the plant stubble high. Hawkins (1958) reported that dairy cattle in Alabama had good weight gain and good milk production while grazing Johnsongrass pasture. King (1950) suggested that overseeding Johnsongrass with Bermudagrass, legumes, sweet clover, Sudangrass or wild winter peas could even further increase the opportunities for grazing Johnsongrass pastures. Rankins and Bransby (1995) conducted a 2-yr study in which stocking rates, production performance and forage intake by steers grazing Johnsongrass pasture were evaluated. Three pastures (1.35, 1.01 and 0.81 ha) with an initial variable stocking rate (3.7 to 9.9 steers per ha) were utilized. In Year 1, increasing the stocking rate on Johnsongrass did not affect ADG or forage intake. In Year 2, increasing stocking rate did not affect forage intake; however, steer ADG and total gain/ha decreased as stocking rate increased, in contrast to findings in Year 1. Overall, Johnsongrass supported an ADG of up to 0.55 kg in a continuous stocking system. In year 1, percentage IVDMD of esophageal masticate samples decreased significantly between June and August sampling periods, indicating that digestibility and nutritive quality decreased with increasing forage maturity. These data also indicated that the stocking rates were likely too low and had thus allowed the forage to mature. In Year 1, esophageal masticate samples also showed a significant increase in both ADF and NDF concentrations between the June and August sampling periods.

*Response to Fertilization*

When considering Johnsongrass response to fertilization, it is necessary to distinguish between inorganic and organic fertilizers. Previous studies on Johnsongrass amended with swine effluent have shown that DM yield response differs between organic and inorganic N fertilizers. Adeli and Varco (2001) reported that, much like that of Bermudagrass, Johnsongrass DM yield increased with increasing levels of N from both inorganic and organic fertilizers. These investigators also found that maximum Johnsongrass yield was obtained at approximately 450 kg N/ha regardless of the source, indicating that additional N did not further increase the yield of the forage. The investigators also showed that, on average, 235 kg N/ha accumulated in plant tissues, with no significant difference between N sources. A similar study conducted by

McLaughlin et al. (2004) revealed that the highest annual DM yield for Johnsongrass was 9.7 Mg/ha, and that up to 188 $kg{\cdot}ha^{-1}{\cdot}yr^{-1}$ of N could be taken up by Johnsongrass. Also, Johnsongrass can take up as much as 23 $kg{\cdot}ha^{-1}{\cdot}yr^{-1}$ of P , which is important because, the higher the P uptake, the more effective the forage will be at maintaining or lowering soil P levels. The investigators also found that, while Johnsongrass yield was not as good as hybrid Bermudagrasses for this purpose, it was comparable to other medium-quality warm-season perennial grasses in the Southeast when fertilized with swine effluent (McLaughlin et al., 2004). These studies indicate that Johnsongrass has the potential to be highly productive when amended with various organic fertilizers, including broiler litter.

## BROILER LITTER

### *Production*

Alabama produces a billion broiler chickens (*Gallus gallus domesticus*) annually, which constitutes 11% of total annual broiler production in the US and makes Alabama the third largest broiler-producing state in the country (USDA, 2007). It is estimated that 0.1 kg of litter is produced for each kg of market weight (Mitchell and Donald, 1999), which translates to approximately 1.4 million Mg of broiler litter produced every yr in the state of Alabama (Paudel et al., 2004). Over half of Alabama's broiler litter production is concentrated within the northeastern portion of the state. According to the 2002 Agriculture Census (USDA, 2002), over 151 million broilers were produced in Cullman County, AL alone.

*Value of Broiler Litter as a Fertilizer*

Broiler litter is a mixture of manure, bedding material, wasted feed, feathers and soil. Bedding material is used to absorb the liquid portion of the excreta and normally consists of either wood chips, sawdust, peanut hulls, wheat straw or recycled paper products (Moore et al., 1998). Land application offers the best and easiest solution for disposal of broiler litter, and more than 90% of broiler litter produced is applied to agricultural land; the remaining 10% is utilized as animal feed (Moore et al., 1995). Broiler litter is considered to be a superior organic fertilizer because of its high DM percentage (75 to 80%) and nutrient content compared with other animal manures (Evers, 1998). Broiler litter routinely contains on the order of 3% total N, 3% $P_2O_5$ and 2% $K_2O$ equivalency, meaning that broiler litter has an average fertilizer grade of 3-3-2 (Mitchell and Donald, 1999). Broiler litter has several advantages compared with commercially produced fertilizers: 1) it contains nutrients required by plants in addition to N, P and K; 2) it contains organic matter that decreases nutrient leaching; 3) organic matter also improves soil structure and water/nutrient-holding capacity; 4) it contains Ca that increases soil pH; and lastly, 5) it is usually more economical than commercial fertilizer (Wood, 1993; Edwards, 1996). Broiler litter contains many microelements required by plants, including Cl, Ca, Mg, Na, Mn, Fe, Cu and Zn (Edwards and Daniel, 1992) that are especially important in poor, weathered soils characteristic of the southeastern US. Because broiler litter contains bedding material (wood chips, peanut hulls, etc.), it contains a large amount of organic matter that contributes to stabilization of soil structure and prevention of soil nutrient leaching as a result of increased soil water-holding capacity, water infiltration rates, cation-exchange capacity and soil tilth (Moore et al., 1998). Kingery et al. (1994) reported that broiler litter increased organic C and total N to soil depths of 30 cm. In addition to containing beneficial micronutrients, broiler litter is also considered more economical than commercial fertilizers for which cost has increased dramatically in the last decade. In order to decrease possible environmental problems from leaching and run-off of excess nutrients, it is important to store litter in a covered shed and synchronize land application with periods of rapid plant growth (Mitchell and Donald, 1999).

*Transportation*

Cost-effective transportation of broiler litter is limited by its high bulk density and low nutrient concentration. Broiler litter production is concentrated in a physiographic region of northeastern Alabama known as Sand Mountain. According to Paudel et al. (2004), only 16 of Alabama's 67 counties produce surplus amounts of broiler litter, with the other 51 counties being deficient in both broiler litter production and utilization.

Pelletier et al. (2001) conducted a survey in which they asked Virginia crop producers whether they were willing to continue or to start utilizing broiler litter as fertilizer for their crops. Nearly every current user indicated a willingness to continue using litter, and nearly all such users expressed a preference for poultry litter over commercial fertilizer. Producers expressed concerns about handling, storage and spreading of litter, as well as potential for increased weed seed germination after using poultry litter. However, Pelletier et al. (2001) reported that most agricultural producers were willing to use broiler litter when and if it was available.

A major obstacle to the transportation of broiler litter is that is it usually restricted to an economic transport distance of 10 to 20 km (Moore et al., 1998), which is largely due to the low nutrient concentration of broiler litter. Assuming broiler litter contains 3.4% N and 1.7% P on a DM basis, a farmer would have to apply five times as much litter as an isonitrogenous quantity of 17-17-17 commercial fertilizer (Moore et al., 1998). Therefore, at long transportation distances, commercial fertilizer becomes more economical than broiler litter.

Paudel et al. (2004) developed an economic model for which the objectives were to minimize the total expenditure on crop nutrients by substituting broiler litter for chemical fertilizer in 20 selected counties of northern Alabama, analyze the economic tradeoff associated with that substitution, select the most efficient transportation routes for transporting the litter, and provide an overview of the economic interdependencies inherent in broiler litter transportation for 29 counties in northern Alabama. Results indicated that total nutrient requirement costs and excess litter problems could be minimized if litter was transported from broiler-producing counties to other counties in Alabama and land-applied on the basis of soil-test P instead of crop requirement for N. The approximate break-even distance was between 106 and 81 km from various counties.

Others have suggested that increasing the bulk density and therefore the nutrient concentration could increase the break-even distance for hauling broiler litter to alternate locations. Moore et al. (1998) suggested that composting or compacting broiler litter could reduce the cost of transportation. Hamilton and Sims (1995) found that pelleting broiler litter turned a normally wet, heterogeneous material that is difficult to apply uniformly into a dried material of a size suitable for application by commercial fertilizer equipment. Also, pelletization or compaction provides the opportunity to enrich relatively low-analysis poultry litters with inorganic fertilizers, producing fertilizer-type blends that are adapted to a greater variety of crops.

*Nitrogen*

Nitrogen is usually the most limiting nutrient for plant growth. Up to a point, DM production by many forages responds linearly to N application. For this reason, N fertilization is one of the most important factors influencing DM yield of warm-season forages. Broiler litter may contain between 17 to 68 g/kg total N; however, not all of the N is immediately available for plant use (Mitchell and Donald, 1999). The principal processes governing the presence of N species within broiler litter are mineralization, volatilization, denitrification, and immobilization (Edwards and Daniel, 1992). The rates at which these processes occur are affected by the soil, amount of precipitation, air and soil temperature, and waste application parameters (Edwards and Daniel, 1992).

The inorganic fraction of total N in broiler litter is available immediately for plant uptake. Nitrogen is a vital component of many cellular processes, including growth, within the plant. Several studies have shown that warm-season forages can routinely assimilate up to 67 kg/ha of N per growing season (Ball et al., 2007). However, only approximately one-third of the total N in broiler litter is in the form of inorganic ammonium ($NH_4$-N). This fraction can be further reduced by volatilization that may occur during storage or immediately following land application of the broiler litter (Edwards and Daniel, 1992). Environmental factors have a large impact on the extent of volatilization that occurs, including temperature, low soil cation-exchange capacity (CEC), high rate of air movement across the soil-waste surface, soil pH, surface application with no soil incorporation, and the $NH_3$ gradient between the soil-waste system and the atmosphere (Reddy et al., 1978). Giddens and Rao (1975) found that 48% of the total N in surface-applied broiler litter volatilized after 10 d of air-drying. Additionally, Wolf et al. (1988) showed that 37% of the total N in surface-applied broiler litter was volatilized in both a 10-d laboratory experiment and 11-d field experiment. These experiments also showed that inorganic N fraction losses were proportional to the total N loss, ranging from 49 to 70% on a clay soil and 58 to 75% on a sandy soil (Edwards and Daniel, 1992). Incorporation of broiler litter into the soil has been shown to significantly decrease volatilization losses (Giddens and Rao, 1975; Wolf et al., 1988); however, incorporation is not the method used routinely by many farmers.

The majority of N in broiler litter is found in the organic fraction, which is not immediately available for plant uptake. Also, it is difficult to predict the pattern and amount of available N released from organic N sources throughout the growing season (Agehara and Warncke, 2005). Soil moisture and temperature are the two major environmental factors that affect mineralization rates of organic N sources. Mineralization of natural organic materials is mediated by heterotrophic bacteria and fungi (Agehara and Warncke, 2005). Franzluebbers (1999) observed that maximum aerobic microbial activity in a Piedmont soil occurred at soil moisture levels between 50 and 70% water-holding capacity. Others have shown that low soil moisture inhibits microbial activity by reducing diffusion of soluble substrates (Griffin, 1981; Schiønning et al., 2003). In contrast, Sistani et al. (2007) conducted both a laboratory and field experiment that showed no significant effect of soil moisture on N mineralization rates. They observed that total inorganic N increased from 23 to 159 mg N/kg soil during a 93-d laboratory experiment. The field studies on three different soil types showed the same trends as the laboratory experiment, but with lower mineralization rates that were attributed to largely environmental factors such as temperature and precipitation. The authors noted that, because soil moisture did not have a significant effect on N mineralization rates, further studies were warranted.

Hubbard et al. (2008) conducted a study to evaluate mineralization of broiler litter as affected by soil texture on two Coastal Plain soils. Two soils were investigated, Tifton loamy sand and Greenville sandy clay loam, N mineralization rates were measured on both broiler litter-amended and non-amended plots, and mineralization rate was determined using net inorganic N values from an anion-exchange resin bed that measured $NO_3$-N leachate from a core sample. The study showed that overall mineralization rates were not different (46.4 mg N/kg soil) between the two differently textured soils; however, sandy type soils mineralized N faster (28 d) than clay type soils (70 d). In general, approximately 40% of N was mineralized within 60 d of broiler litter application. Also, further mineralization of N did not occur in subsequent growing seasons.

Leaching of N into groundwater systems can have a detrimental effect on the environment, as well as human and animal health. Nitrogen has been linked to eutrophication of water sources polluted by water runoff from fields fertilized with broiler litter (Edwards and Daniel, 1992). Nitrate-N ($NO_3$-N) in runoff water has been linked to Blue Baby Syndrome in infants and nitrate toxicity in ruminants, especially cattle consuming polluted water; both toxicities can be fatal if left untreated (Edwards and Daniel, 1992). Wood et al. (1999) found that, with an average application rate of 18 Mg/ha of broiler litter, 3.20 mg/L of $NO_3$-N were observed in water runoff from corn fields. According to Birge and Juday (1992), Chu (1943), Hutchinson (1957) and Sawyer (1947), 5.3 mg/L N are necessary to cause an algal eutrophication event, but even trace quantities have been documented to cause eutrophication (Wood et al., 1999).

*Phosphorus*

Phosphorus is essential for plant growth, much like N; however, it is needed by plants in lesser amounts. Also, much like N, the environmental fate of the P fraction present in broiler litter, and therefore in the soil, are dependent on the processes of mineralization, precipitation/sorption, and plant uptake (Reddy et al., 1978). Sharpley and Moyer (2000) have reported that up to 88–90% of total P is in the inorganic form and readily plant-available. Consequently, broiler litter is considered a good source of P, potentially equivalent to inorganic fertilizer (Malone, 1992).

When applying broiler litter on the basis of crop N requirement, phosphorus is applied at rates that exceed plant requirements and can therefore become a threat to the environment. Most plants require a N: P ratio of approximately 8:1; broiler litter N: P ratio can be as low as 2.3:1 (Barker et al., 2004). Adeli et al. (2005) reported that the amount of water-soluble P (WSP), generally considered to be potentially most harmful to the environment, was largely dependent on soil type in a comparison of a silty clay, silt loam and sandy loam soils. They also observed that temperatures greater than 32°C promoted higher biological activity and thus a lower WSP fraction in the soil. Wood et al. (1999) have shown that a broiler application rate of 18 Mg/ha to a corn field produced runoff water containing up to 2.00 mg total P/L. Of the total P, 1.43 mg/L was dissolved P, which is the fraction most available to algae and therefore a main cause of eutrophication. Pierson et al. (2001) found that fertilization with broiler litter at a rate of 271 to 483 kg N/ha increased surface runoff levels of dissolved-reactive P from background levels of 0.4 mg/L to values greater than 18 mg/L immediately after a third application of broiler litter. However, the dissolved-reactive P concentrations decreased linearly with the natural logarithm of days after application, and increased linearly with the natural logarithm of runoff volume.

Soil accumulation of P can be quite substantial; however, Sharpley et al. (1993) found that, at soil depths below 30 cm, very little P accumulation occurred. They also found that P accumulation in surface soils was greatest in soils with large quantities of Fe and Al oxides that adsorb P. Gascho and Hubbard (2006) found that the buildup of P extracted by Mehlich-1 after 5 yr of broiler litter application increased more than 100 ppm in the top 15 cm of the soil with an application rate of 13.5 Mg /ha of non-incorporated broiler litter. The authors suggested that such an increase in surface-soil P could increase the potential for losses of P into water bodies. Schomberg et al. (2009) reported that repeated broiler litter application for 10 yr caused a greater than 300 kg/ha increase in Mehlich-1 extractable P in the top 15 cm of the soil surface. The authors, much like Gascho and Hubbard (2006), suggested that such a P increase was very likely to harm surrounding water bodies and possibly cause eutrophication.

*Other Macronutrients*

Broiler litter contains not only N and P but also many other plant macronutrients and micronutrients, including Ca, Cu, K, Mg and Zn. As broiler litter application rate increases, soil surface concentrations of K also increase (Sistani, 2004). Mitchell and Tu (2006) found that soil Mehlich-1 extractable K initially accumulates in the surface soil horizons; by the end of 10 yr, leaching was apparent and soil surface K had decreased significantly. They also observed a significant relationship between extractable K and broiler litter application rates. Wood et al. (1999) reported that sediment K concentrations in surface runoff were not different between commercial fertilizer (ammonium nitrate and triple super phosphate) and broiler litter applied at a rate of 18 Mg/ha; concentrations of sediment K were 0.48, 0.41and 0.45 for commercial fertilizer, broiler litter applied at 9 Mg/ha and broiler litter applied at 18Mg/ha, respectively.

Broiler litter can also contain high concentrations of Ca that can accumulate in soils. Both long-term and short-term applications of broiler litter to soil can cause a significant increase in Ca concentrations that can lead to losses via runoff (Wood et al., 1999). Mitchell and Tu (2006) found that application of broiler litter at a rate of 269 kg

N/ha increased accumulation of extractable Ca in surface soil by 28% compared with a control plot. Accumulation was greatest at 0- to 20- cm soil depth, similar to results of Kingery et al. (1994) who reported a difference of 800 mg/kg in surface soil Ca concentration between control and long-term broiler litter applications of 6 to 22 $Mg \cdot ha^{-1} \cdot yr^{-1}$. Kingery et al. (1994) also showed that, with long-term application of broiler litter, Ca migrated to a depth of 140 cm in the soil.

Magnesium can accumulate in soils amended with broiler litter. Kingery et al. (1994) reported an increase in Mg concentration of 50 mg/kg at the surface of soils receiving broiler litter. However, at depths of 230 to 290 cm, littered versus non-littered soils differed by only 16.5 mg/kg. Other studies, including that of Mitchell and Tu (2006), have also shown a positive relationship between Mg concentration in soil and application rate of broiler litter. At a depth of 0 to 15 cm, Mg concentration was 23% higher in soils receiving 269 kg N/ha broiler litter compared with a non-fertilized control. Wood et al. (1999) reported no difference between dissolved Mg and sediment Mg concentrations in runoff from plots of corn or rye fertilized with commercial fertilizer, 9 Mg/ha broiler litter or 18 Mg/ha broiler litter. These studies indicate that, while soil concentrations of Mg increase with increasing rates of broiler litter application, surface runoff is not affected; however, with greater application rates or longer periods of application, these relationships could change.

*Micronutrients*

Due to the levels of Zn utilized in broiler diets, Zn concentrations in broiler litter can be high. Stephenson et al. (1990) reported concentration of Zn in broiler litter of 315 mg/kg DM. Wood et al. (1999) observed that dissolved Zn in surface runoff from corn plots was significantly higher, 0.61 vs. 0.36 mg/ L, from commercial fertilizer than broiler litter applied at 18 Mg/ha. Kingery et al. (1994) observed that Zn accumulated in surface soils up to a depth of 45 cm. Gascho and Hubbard (2006) reported a five-fold increase in surface soil Zn concentration in broiler litter-amended soils compared with a control. However, these levels were not sufficiently high to pose a potential environmental pollution problem. Continued application of broiler litter may lead to Zn levels in soils that could possibly cause a toxicity problem in subsequent crop plantings.

Copper can also be found in high concentrations in broiler litter because it is used as an additive in poultry feed. Accumulation of Cu in soil may cause adverse effects on plant growth and activity of aquatic organisms (Pierzynski et al., 2000); therefore, it is necessary to carefully monitor concentrations of Cu in broiler litter as well as in soil. Mitchell and Tu (2006) reported that, over a 13-yr period, tested broiler litter contained an average of 586 mg/kg of Cu. In a previous report from the same study, they found that increasing broiler litter application rate increased Cu concentrations in the leaves of both corn and cotton (Mitchell and Tu, 2005). Edwards and Daniel (1992) reported that Cu concentration in broiler litter ranged from 25 to 127 mg/kg, which is considerably lower than that in the previous study; however, concentration of Cu is largely determined by amount of feed additive added to poultry diets in order to increase weight gain and prevent disease. Franzluebbers et al. (2006) reported mean soil surface (i.e., 0 to 3 cm) concentrations of 26 mg Cu/kg. They also found that concentrations were higher under an intensive put-and-take rotational grazing system than a less intensive, continuous grazing system. Additionally, Cu concentrations were lowest in both the 0- to 3-cm and the 3- to 6-cm soil depths with a monthly hayed system.

*Compaction of Broiler Litter*

Compaction of broiler litter (i.e., volume reduction, increase in bulk density) may allow for easier and more economical transport to locations distant to areas of concentrated poultry production. Compaction is achieved through a pressurized process, usually pelleting. However, Sturgeon (2008) conducted a study in which compaction was achieved through fabrication of broiler-litter bricks (30.5 cm × 30.5 cm × 20 cm). Pelleting is achieved by grinding and forcing the ground sample through a die that has a diameter typically of 4 to 12 mm (McMullen et al., 2005). Creating pellets decreases the storage space needed; however, storage of pellets originating from a biological source requires proper ventilation because spoilage can occur over time (Maier and Bakker-Arkema, 1989).

McMullen et al. (2005) conducted a study to determine storage and handling characteristics of pellets made from boiler litter with hardwood shaving as bedding material. They were able to increase the bulk density of the poultry litter from 200 $kg/m^3$ (raw form) to between 770 and 790 $kg/m^3$ in pellets, and also discovered that increasing moisture content of the litter slightly decreased the bulk density of the pellets. Durability of the pellets was determined as a ratio of post-tumbling weight, in which 100 g pellet were tumbled at 50 rpm for 10 min, to initial weight of pellet. Durability of the pellets ranged from 88 to 95% within a range of moisture concentration of 6 to 22%, and increased with increasing moisture concentration up to 10%, at which maximum durability was reached. At greater than 10 % moisture, the durability of the pellets decreased due to volume expansion of the pellets. Hardness of the pellets decreased linearly with increasing moisture concentration of the litter, and moisture content did not significantly affect bulk thermal conductivity and thermal diffusion of the pellets. These data are important for determining the appropriate storage method for compacted poultry litter.

Hamilton and Sims (1995) conducted an experiment in which they determined the availability of N and P in broiler-litter pellets that had been enriched with diammonium phosphate (DAP, $(NH_4)_2PO_4$) and potassium chloride (KCl), or not enriched. A control of inorganic N ($NH_4NO_3$) in combination with the DAP was compared with the broiler litter treatments in a 16-wk laboratory study that was conducted to measure N and P mineralization rates in Hammonton loamy sand and Pocomoke black loamy sand soils. Nitrification occurred rapidly in both soils; however, some N loss from the plant-available fraction occurred, possibly from microbial immobilization or denitrification that resulted in an approximately 50% decrease in available N within 6 wk in the poultry litter-enriched plots. Soluble P increased by 20–25 mg P/kg and 7–12 mg P/kg in soils fertilized with enriched broiler litter and broiler litter, respectively; however, it rapidly reverted to the less soluble forms. The average recovery of P from the enriched broiler-litter soils after 16 wk was greater in the Pocomoke soil (15%) than in the Hammonton soil (5%), suggesting that soil organic matter may have inhibited P fixation. A greenhouse study was also conducted using corn and tomato plants. The investigators observed that, when applied at the correct rate, enriched broiler litter pellets were generally more effective and consistent N sources than broiler litter pellets alone. Enriched broiler litter pellets could also produce comparable yields and N uptakes in corn and tomato plants to those of the DAP treatment. The observed N recoveries indicated that, under the more dynamic conditions of a greenhouse, both corn and tomato plants could effectively take up N from enriched boiler litter pellets.

Sturgeon (2008) used a method of compaction that involved fabrication of 30.5 cm × 30.5 cm × 20 cm bricks. Compaction was achieved by layering the broiler litter into a square die and using a hydraulic press. The investigator recorded bulk density, pH, electrical conductivity, and concentrations of C, N, P, K, Ca, Mg, Fe, Cu and Zn when the broiler litter bricks were initially made, as well as periodically for one year. The moisture content of the broiler litter had to be increased to facilitate the compaction process, which changed the pH and the concentration of certain nutrients. Concentrations of Cu and Fe decreased 3%, electrical conductivity decreased 4%, and pH increased with the addition of water to the broiler litter. Samples were then tested to determine the differences caused by the compaction process. Wet samples and compacted samples were compared, and concentrations of Ca, Na and P decreased during the compaction process by 5, 3 and 2%, respectively. Over the course of one year, total N loss was approximately 5 g/kg, while $NH_4$-N and $NO_3$-N losses totaled approximately 3.5 g/kg of total N.  Magnesium concentrations and pH initially increased and then decreased over time to values lower than those in initial samples. Calcium followed a similar pattern; however, the final concentration was similar to that of the initial sample.  Concentrations of K, Cu and Fe levels also followed a similar pattern of increasing initially and then decreasing; however, final concentrations were higher than those measured initially. Phosphorus and Na concentrations remained consistent over time, likely because the available forms of these nutrients are not volatile.  Carbon concentrations decreased over time; however, this decrease was not as great as that reported by Flynn (1995). Concentrations of Zn increased throughout the experimental period.

Changes in nutrient concentrations and nutrient availability occur during the compaction process and during storage of compacted broiler litter material.  In general, these changes are not biologically significant because they are so miniscule. Compaction offers the possibility of transporting broiler litter from areas of high broiler litter production to areas that could benefit from a less expensive source of forage nutrients.

## II. PRODUCTIVITY AND NUTRITIVE QUALITY OF JOHNSONGRASS AS INFLUENCED BY INTERSEEDED LADINO CLOVER AND FERTILIZATION WITH COMMERCIAL FERTILIZER OR BROILER LITTER

### INTRODUCTION

Broiler litter is a mixture of manure and bedding material. Bedding material is used to absorb the liquid portion of the excreta and usually consists of cellulosic materials such as wood shavings, peanut hulls, sawdust, wheat straw or recycled paper products. Within the state of Alabama alone, approximately 1.36 million metric tons of broiler litter are produced annually (Mitchell and Donald, 1999). Over 90% of broiler litter is disposed of through land application (Edwards and Daniel, 1992). Therefore, in regions of high poultry production, soils have become concentrated with nutrients as a result of repeated land application of broiler litter over the past several decades. Within the state of Alabama, the broiler industry is concentrated in the Sand Mountain region in the northeastern portion of the state. The top four broiler-producing counties within the state – Cullman, Blount, Marshall and Dekalb – are all located within this area (USDA, 2007). Studies have shown that repeated land application of animal manures to fields can potentially cause environmental problems. Phosphorus runoff and resulting eutrophication is one of the most common environmental problems associated with organic fertilizers (Edwards and Daniel, 1992).

High-producing warm-season forages have significant capacity for assimilating nutrients from land-applied broiler litter (Ball et al., 2007; Fraps and Fridge, 1940). In the past, Bermudagrass has been very successful in producing high biomass yields, and in doing so reducing adverse effects of broiler litter application on soil quality. Studies have shown that Johnsongrass can produce as much or more biomass than common Bermudagrass, making it an attractive candidate for nutrient management.

Broiler litter is commonly land-applied on the basis of crop requirement for N; however, this practice has resulted in elevated levels of soil P, especially in the Sand Mountain region (Wood et al., 1993). Low nutrient concentration and bulk density make long-distance transportation of broiler litter cost-prohibitive (Sharpley et al., 1993); however, pressure-compaction of broiler litter increases its nutrient concentration and bulk density, conceivably making its transportation more economically feasible. Pressure-compaction may thus enable cost-effective transport of broiler litter from areas of intensive poultry production to areas of poor soil fertility in Alabama's Black Belt region. Also, application of broiler litter on the basis of soil-test P may prevent build-up of P in these soils and thus minimize environmental hazards associated with land application of organic fertilizers.

# MATERIALS AND METHODS

*Research site*

The experiment was conducted in the summers of 2007 and 2008 at the Black Belt Research and Extension Center in Marion Junction, AL (32º 28’50.29”N latitude, 87º15’26.61”W longitude, 57 m above MSL). Twenty-four field plots (3 × 6 m ea.) consisting of Vaiden and Houston clay soils were demarcated and treated on June 8, 2007 with glyphosate at a rate of 4.7 L/ha to kill existing vegetation . Plots were tilled on June 15 and seeded on June 18, 2007. Plots were organized into four blocks (replicates), each of which comprised six plots representing six experimental treatments. Soil nutrient ratings and values were determined, and fertilization recommendations were made on the basis of soil tests conducted by the Auburn University Soil Testing Laboratory.

*Compaction of broiler litter*

Broiler litter was collected from a poultry operation in Talladega County, AL and transported to Auburn University. Initial concentration of moisture in litter was determined using a Model IR-200 moisture analyzer (Denver Instruments, Arvada, CO). Water was then added to and mixed with a portion of the litter in a concrete mixer to achieve a moisture concentration of approximately 40%. Immediately after mixing, moistened litter was subjected to 192 MPa of pressure for 1 min until 4 layers of litter were compacted into a cube. Each cube measured approximately 30.5 × 30.5 × 20 cm. Bricks were stored for 5 d before they were chipped using a commercial mulch chipper and then transported with a load of non-compacted broiler litter to Marion Junction, AL and applied to plots.

*Forage establishment, management and harvesting*

Johnsongrass (*Sorghum halepense*) was seeded into all plots at a recommended rate of 28 kg/ha, and ladino clover (*Trifolium repens* cv. 'Regal Graze') was seeded into half of the plots in each block at a rate of 5.6 kg/ha to achieve a 1:4 ratio of clover to Johnsongrass. Plots were fertilized on June 18, 2007 with compacted broiler litter (BL), non-compacted BL (BL-N) or commercial fertilizer (CF) such that each clover-status × fertilizer-source treatment was represented once in each block (Figure 1). The CF was a mixture of ammonium nitrate (34-0-0) and diammonium phosphate (18-46-0) that was formulated to provide the equivalent of 56.0 kg $P_2O_5$, 44.8 kg $K_2O$ and 67.3 kg N/ha. Broiler litter application rate was determined on the basis of soil-test P, and litter-amended plots were supplemented with additional N from ammonium nitrate in order to meet the recommended rate of N application (67.3 kg N/ha) and be isonitrogenous with CF. All fertilizer was applied by hand and soil-incorporated prior to initial planting. In May, 2008, fertilizer was hand-applied onto the soil surface but not incorporated so as to not damage plant tissues.

Primary-growth forage was harvested in each year of the experiment (August 9, 2007 and August 1, 2008) when Johnsongrass reached a late-vegetative (boot) stage of maturity, followed by a second harvest of vegetative-regrowth forage (October 2, 2007 and September 22, 2008). Forage was cut with a flail-chopping mower to leave an aboveground stubble height of approximately 10 cm. Fresh-cut forage was weighed on a portable scale, and a sample from each plot was then placed into a tared paper bag and weighed. Samples were oven-dried at 60º C for 72 hr, and DM yield was calculated for each plot based on dry-weight data.

Block1

| | | |
|---|---|---|
| CF<br>CLO | BL-C<br>CLO | BL-N<br>CLO |
| CF<br>PUR | BL-N<br>PUR | BL-C<br>PUR |

Block 2

| | | |
|---|---|---|
| BL-N<br>CLO | CF<br>CLO | BL-C<br>CLO |
| BL-N<br>PUR | CF<br>PUR | BL-C<br>PUR |

Block 3

| | | |
|---|---|---|
| CF<br>PUR | BL-N<br>PUR | BL-C<br>PUR |
| BL-N<br>CLO | CF<br>CLO | BL-C<br>CLO |

Block 4

| | | |
|---|---|---|
| BL-N<br>PUR | CF<br>PUR | BL-C<br>PUR |
| CF<br>CLO | BL-C<br>CLO | BL-N<br>CLO |

Overall Field Layout

| | | | | | |
|---|---|---|---|---|---|
| East | Block 1 | Block 2 | Block 3 | Block 4 | West |

Figure 1. Layout of experimental plots

*Laboratory analyses*

Dried, air-equilibrated samples were ground in a Wiley mill to pass a 1-mm screen, and final concentration of DM was determined by oven-drying at 100º C according to procedures of AOAC (1995). Forage concentration of N was determined by the Kjeldahl procedure (AOAC, 1995), from which CP was calculated as N × 6.25. Concentrations of NDF, ADF and ADL were analyzed by procedures of Van Soest et al. (1991). Hemicellulose was calculated as NDF minus ADF. Relative feed value (RFV; Rohweder et al., 1978) was calculated from concentrations of NDF and ADF according to Linn and Martin (1989). Forage samples were prepared for mineral analyses by dry-ashing, wet-digestion with 1N $HNO_3$ and solubilization in 1N HCL (Hue and Evans, 1986), and concentrations of P, K, Ca, Cu, Mg, Al, Fe and Zn were then determined by inductively coupled argon plasma (ICAP) spectroscopy (Spectro Ciros CCD, Germany).

*Statistical analysis*

Data were analyzed using the PROC MIXED procedure (SAS Inst. Inc., Cary, NC) for a complete block design with a 2 × 3 factorial arrangement of treatments (4 replicates per treatment). Independent variables included block (replicates), clover status, fertilizer source and the clover-status × fertilizer-source interaction. Vegetative regrowth harvests were treated as repeated measures of primary harvests, and year was considered as a random effect in the statistical model. Treatment means were separated by the LSMEANS procedure (SAS Inst. Inc., Cary, NC) when protected by F-tests significant at $\alpha$ of 0.10, and are reported as least squares means ± SE.

# RESULTS

*Temperature and precipitation*

During the experimental period, monthly mean air temperatures were slightly higher than 30-yr averages for Marion Junction, AL (Table 1). For the months of June, July and August 2007, monthly precipitation was 11, 46 and 25% lower, respectively, than the 30-yr average (Table 2). In 2008, June and July monthly precipitation was 13 and 53% lower, respectively, than the 30-yr average. Precipitation in August 2008 was 171% higher than the 30-yr average; however, total precipitation in September 2008 was 96% lower than the 30-yr average for Marion Junction. Total precipitation for the months during the experimental period was 61 and 17% below the 30-yr average in 2007 and 2008, respectively.

Table 1. Monthly mean air temperatures (°C) for May–October 2007 and 2008, and 30-yr averages for Marion Junction, AL

| Month | 2007 | 2008 | 30-yr avg. |
|---|---|---|---|
| May | 22 | 22 | 22 |
| June | 26 | 27 | 26 |
| July | 29 | 27 | 27 |
| August | 29 | 26 | 27 |
| September | 24 | 24 | 24 |
| October | 18 | 17 | 18 |

Table 2. Monthly total precipitation (mm) for May–October 2007 and 2008, and 30-yr averages for Marion Junction, AL

| Month | 2007 | 2008 | 30-yr avg. |
|---|---|---|---|
| May | 3 | 78 | 104 |
| June | 101 | 98 | 113 |
| July | 70 | 61 | 129 |
| August | 64 | 230 | 85 |
| September | 67 | 4 | 100 |
| October | 66 | 33 | 75 |
| Total | 371 | 504 | 606 |

*Dry matter yield*

No differences ($P$ = 0.2036) were observed between Johnsongrass and Johnsongrass-clover forage, or among fertilizer-source treatments ($P$ = 0.8378) for DM yield (Table 3).

Table 3.Yield (kg DM/ha) of Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 7,590 | 6,555 | 7,073 |
| BL-N | 6,656 | 6,810 | 6,733 |
| BL-C | 7,314 | 6,208 | 6,761 |
| Mean[2] | 7,187 | 6,524 | |

[1]SE = 1,853.
[2]SE = 1,835.

*Crude protein*

Crude protein concentration was higher ($P = 0.0735$) in Johnsongrass-clover than Johnsongrass forage (Table 4), and was not different ($P = 0.6018$) among the three fertilizer-source treatments.

Table 4. Concentration (%, DM basis) of CP in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 10.2 | 10.6 | 10.4 |
| BL-N | 10.0 | 10.5 | 10.3 |
| BL-C | 9.7 | 10.4 | 10.0 |
| Mean | 9.9[a] | 10.5[b] | |

[1]SE = 2.08.
[a,b]Within a row, means without a common superscript differ ($P = 0.0735$; SE = 2.08).

*Cell wall constituents and RFV*

Neutral detergent fiber concentration was not different ($P = 0.1301$) between Johnsongrass and Johnsongrass-clover forage (Table 5) or among fertilizer-source treatments ($P = 0.2210$). Similarly, concentration of ADF was not different ($P = 0.9678$) between Johnsongrass and Johnsongrass-clover forage (Table 6) or among fertilizer-source treatments ($P = 0.8341$). However, a forage × fertilizer source interaction ($P = 0.0982$) was observed such that Johnsongrass fertilized with BL-N had lower ($P = 0.0808$) ADF concentration than CF-amended Johnsongrass. Also, Johnsongrass amended with CF had higher ($P = 0.0750$) concentration of ADF than CF-amended Johnsongrass-clover. Hemicellulose concentration was higher ($P = 0.0854$) in Johnsongrass-clover than Johnsongrass forage (Table 7), and higher ($P = 0.0526$) in BL treatments than the CF treatment. Interseeding with clover had no effect ($P = 0.7373$) on forage concentration of ADL (Table 8); also, fertilizer source did not affect ($P = 0.3420$) ADL concentration. However, a forage × fertilizer source interaction ($P = 0.0507$) was observed such that ADL concentration was higher ($P = 0.013$) in CF- than BL-N-amended Johnsongrass, and within CF forages was higher ($P = 0.0407$) for Johnsongrass than Johnsongrass-clover. Relative feed value (Table 9) did not differ ($P = 0.9345$; $P = 0.4175$) between forage or among fertilizer-source treatments.

Table 5. Concentration (%, DM basis) of NDF in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 63.2 | 64.2 | 63.7 |
| BL-N | 63.8 | 66.8 | 65.3 |
| BL-C | 65.4 | 67.2 | 66.3 |
| Mean[2] | 64.1 | 66.0 | |

[1]SE = 1.43.
[2]SE = 1.29.

Table 6. Concentration (%, DM basis) of ADF in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 36.3[a] | 34.8[b] | 35.5 |
| BL-N | 34.8[b] | 35.6 | 35.2 |
| BL-C | 35.2 | 35.8 | 35.5 |
| Mean[2] | 35.4 | 35.4 | |

[a,b]Within a column, means without a common superscript differ ($P$ = 0.0808).
[a,b]Within a row, means without a common superscript difer ($P$ = 0.0750).
[1]SE = 0.89.
[2]SE = 0.85.

Table 7. Concentration (%, DM basis) of hemicellulose in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean |
|---|---|---|---|
| CF | 26.9 | 29.4 | 28.1[a] |
| BL-N | 29.0 | 31.2 | 30.1[b] |
| BL-C | 30.2 | 31.3 | 30.8[b] |
| Mean | 28.7[a] | 30.6[b] | |

[a,b]Within a column, means without a common superscript differ ($P$ = 0.0526; SE = 2.0).
[a,b]Within a row, means without a common superscript differ ($P$ = 0.0854; SE = 2.1).

Table 8. Concentration (%, DM basis) of ADL in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 3.4[a] | 3.1[b] | 3.2 |
| BL-N | 3.0[b] | 3.2 | 3.1 |
| BL-C | 3.2 | 3.2 | 3.2 |
| Mean[2] | 3.19 | 3.17 | |

[a,b]Within a column, means without a common superscript differ ($P = 0.013$).
[a,b]Within a row, means without a common superscript difer ($P = 0.0407$).
[1]SE = 0.58.
[2]SE = 0.58.

Table 9. Relative feed value (RFV) of Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)[1]

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[2] |
|---|---|---|---|
| CF | 87.0 | 89.1 | 88.0 |
| BL-N | 89.8 | 87.4 | 88.6 |
| BL-C | 87.0 | 87.1 | 87.0 |
| Mean[3] | 87.9 | 87.8 | |

[1]Relative feed value, standardized by reference to a mature legume hay containing 53% NDF, 41% ADF and RFV of 100 (Linn and Martin, 1989).
[2]SE = 0.69.
[3]SE = 0.84.

*Macrominerals*

Foliar concentration of Ca was not different (*P* = 0.1246) between forages (Table 10) or among fertilizer-source treatments (*P* = 0.8069). The Johnsongrass-clover mixture had higher (*P* = 0.0022) foliar concentration of K than Johnsongrass (Table 11), and BL-amended forages tended to have higher (*P* = 0.1224) foliar concentration of K than CF-amended forage. Foliar concentration of P was not different (*P* = 0.3064) between forages (Table 12) or among fertilizer-source treatments (*P* = 0.5035). Johnsongrass-clover forage had higher (*P* = 0.0001) concentration of Mg than Johnsongrass (Table 13), but concentrations of Mg were not different (*P* = 0.6776) among fertilizer-source treatments.

Table 10. Concentration (%, DM basis) of Ca in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 0.51 | 0.47 | 0.49 |
| BL-N | 0.49 | 0.48 | 0.49 |
| BL-C | 0.48 | 0.49 | 0.49 |
| Mean[2] | 0.50 | 0.48 | |

[1]SE = 0.016.
[2]SE = 0.015.

Table 11. Concentration (%, DM basis) of K in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 0.85 | 1.01 | 0.93 |
| BL-N | 0.99 | 1.09 | 1.04 |
| BL-C | 0.93 | 1.09 | 1.01 |
| Mean | 0.92[a] | 1.06[b] | |

[1]SE = 0.038.
[a,b]Within a row, means without a common superscript differ (*P* = 0.0022; SE = 0.031).

Table 12. Concentration (%, DM basis) of P in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 0.17 | 0.17 | 0.17 |
| BL-N | 0.18 | 0.17 | 0.18 |
| BL-C | 0.18 | 0.18 | 0.18 |
| Mean[2] | 0.18 | 0.17 | |

[1]SE = 0.039.
[2]SE = 0.039.

Table 13. Concentration (%, DM basis) of Mg in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 0.44 | 0.37 | 0.41 |
| BL-N | 0.40 | 0.39 | 0.40 |
| BL-C | 0.41 | 0.38 | 0.40 |
| Mean | 0.42[a] | 0.38[b] | |

[1]SE = 0.021.
[a,b]Within a row, means without a common superscript differ ($P$ < 0.0001, SE = 0.021).

*Microminerals*

There were no differences in foliar Al concentration (Table 14) between forages ($P$ = 0.9609) or among fertilizer-source treatments ($P$ = 0.3921). Similarly, foliar concentration of Cu (Table 15) was not different between forages ($P$ = 0.2611) or among fertilizer-source treatments ($P$ = 0.4592). Concentration of Fe (Table 16) was not different between forages ($P$ = 0.9514) or among fertilizer-treatments ($P$ = 0.4214). No difference ($P$ = 0.8697) was observed between Johnsongrass and Johnsongrass-clover in foliar Zn concentration (Table 17). Forages amended with CF had a lower foliar Zn concentration than both BL-N ($P$ = 0.0223) and BL-C ($P$ = 0.0636) treatments, but there was no difference ($P$ = 0.6561) in foliar Zn concentration between the BL-N and BL-C treatments.

Table 14. Concentration (mg/kg, DM basis) of Al in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 1,896 | 2,755 | 2,326 |
| BL-N | 2,621 | 1,905 | 2,263 |
| BL-C | 1,837 | 1,745 | 1,791 |
| Mean[2] | 2,118 | 2,135 | |

[1]SE = 900.
[2]SE = 880.

Table 15. Concentration (mg/kg, DM basis) of Cu in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 4.5 | 5.1 | 4.8 |
| BL-N | 5.4 | 5.9 | 5.6 |
| BL-C | 4.9 | 5.7 | 5.3 |
| Mean[2] | 5.0 | 5.6 | |

[1]SE = 0.60.
[2]SE = 0.54.

Table 16. Concentration (mg/kg, DM basis) of Fe in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean[1] |
|---|---|---|---|
| CF | 951 | 1,406 | 1,178 |
| BL-N | 1,365 | 932 | 1,149 |
| BL-C | 886 | 901 | 894 |
| Mean[2] | 1,168 | 1,179 | |

[1]SE = 384.0.
[2]SE = 372.

Table 17. Concentration (mg/kg, DM basis) of Zn in Johnsongrass and Johnsongrass-clover forage amended with commercial fertilizer (CF), non-compacted broiler litter (BL-N) or compacted broiler litter (BL-C)

| Fertilizer source | Johnsongrass | Johnsongrass-clover | Mean |
|---|---|---|---|
| CF | 37.6 | 37.2 | 37.4[a] |
| BL-N | 40.9 | 40.7 | 40.8[b] |
| BL-C | 40.2 | 40.1 | 40.1[a,b] |
| Mean[1] | 39.5 | 39.3 | |

[a,b] Within a column, means without a common superscript differ (*P* = 0.0526, SE = 2.05).
[1]SE = 1.96.

# DISCUSSION

Ball et al. (2007) have reported that Johnsongrass can routinely produce between 4,500 and 11,200 kg of hay/ha over an entire growing season. In the current experiment, DM yield averaged 6,856 kg/ha for each harvest across years, forages and fertilizer-source treatments. In the first year (2007), cumulative yield of primary-growth and vegetative-regrowth harvests averaged 10,078 kg/ha across forages and fertilizer-source treatments. In the second year (2008), the corresponding value for seasonal productivity was 17,344 kg/ha across forages and fertilizer-source treatments. In 2007, total annual precipitation was 61% lower than the 30-yr average for Marion Junction, AL; however, forage production was still within the range of typical seasonal yields reported by Ball et al. (2007), which illustrates the ability of Johnsongrass to withstand significant drought (McWhorter, 1993). In 2008, total annual rainfall was only 17% below the 30-yr average, which provided more optimal conditions for growth. Total seasonal productivity of forages in 2008 illustrates the exceptionally high productivity potential of this warm-season grass. McLaughlin et al. (2004) observed a 283% increase in DM yield of Johnsongrass in a comparison of years characterized by adequate or suboptimal rainfall. These authors reported a cumulative seasonal production of up to 9,700 kg DM/ha for Johnsongrass that had been amended with swine effluent and harvested four times throughout the growing season. Monthly average temperatures ranged from 18 to 29º C in the present study, which is well within optimum range for growth of Johnsongrass (Hull, 1970).

Yield of DM did not differ between Johnsongrass and Johnsongrass-clover forage, which was somewhat unexpected. Overman et al. (1992) observed an increase in total forage production for Bermudagrass interseeded with clover compared with pure Bermudagrass grown in the Southern Piedmont. In the present study, the pattern and aggressiveness of growth of Johnsongrass may have been such that it outcompeted the interseeded clover for growth resources (water, light, etc.). For this reason, it is conceivable that the Johnsongrass component of the mixed-species forage treatment did not allow the clover to reach its full growth potential. Also, there were no differences in forage production among the fertilizer-source treatments. Evers (1998) reported that, in the second year of his experiment, yield of Coastal Bermudagrass was 1,120 kg DM/ha higher from plots fertilized with broiler litter than from plots receiving commercial fertilizer of N concentration similar to that of broiler litter. Wood et al. (1993) attributed additional productivity from broiler litter to additional mineralization of organic N that had been applied the previous year, increased soil organic matter, and other benefits of applying animal waste to acidic, sandy soils. Results of the present study also demonstrate that compaction of broiler litter did not affect its replacement value for commercial fertilizer as a source of nutrients for forage production from Johnsongrass.

Crude protein ($N \times 6.25$) is an important determinant of nutritive quality of forages. Johnsongrass interseeded with clover contained 6% more CP than Johnsongrass alone, which was expected because legumes normally have a higher concentration of protein than grasses (Stringer et al., 1996). Alfalfa, for example, routinely contains approximately 20% or more CP, which is much higher than that in most forage grasses

(Van Soest, 1994; Ball et al., 2007). In the present study, mean foliar concentration of CP was 10.2% across forages and fertilizer-source treatments, which is more than adequate to support maintenance of a mature, non-lactating beef cow and modest ADG in a growing beef steer (NRC, 1996). Fertilizer source did not have an effect on CP concentration. Ladino clover has approximately of 26% CP, and sorghum-sudangrass has approximately 9% CP (NRC, 1996). Using these values, only 3-5% clover in the stand would have been necessary to attain the 10.5% CP observed in the clover-Johnsongrass forage mixture, which is lower than the original goal of 25% clover in the stand. Wood et al. (1993) observed no difference in CP concentration in Bermudagrass that had been fertilized with ammonium nitrate or broiler litter, although CP concentration differed among forages receiving different rates of N application. In the current study, N-application rates were uniform among all fertilizer-source treatments. Across years, forages and fertilizer-source treatments, regrowth harvests contained 9% less CP than primary-growth harvests. Similarly, Johnson et al. (2001) reported that CP concentration declined over a growing season in Bermudagrass that had been harvested multiple times.

Concentration of CP alone is not a fully satisfactory predictor of forage nutritive quality across a broad range of growing conditions, and other factors such as concentrations of cell-wall constituents (i.e., fiber) are generally more important than CP concentration as determinants of forage nutritive quality (Rohweder et al., 1978). Neutral detergent fiber consists of partially and non-uniformly digestible fractions of total cell-wall constituents that are inversely related to voluntary DM intake, whereas ADF includes the least digestible and indigestible cell-wall constituents that are inversely related to DM digestibility (Van Soest, 1994). Foliar concentration of NDF across forages and fertilizer-source treatments was 65.1% in the present study. Similarly, Adeli et al. (2005) reported a range of 63.9 to 66.7% NDF in Johnsongrass that had been fertilized with swine effluent. Neutral detergent fiber concentrations were not different between Johnsongrass and Johnsongrass-clover forages, or among fertilizer-source treatments. Previous studies have shown a significant decrease in NDF concentration in Bermudagrass grown in mixture with a legume (Stringer et al., 1996, Sleugh et al., 2000), consistent with the agronomic generalization that concentration of NDF in legumes is typically lower than that of grasses when compared at comparable stages of physiological maturity (Van Soest, 1994). While NDF concentration was expected to be lower for Johnsongrass-clover forage than Johnsongrass for this reason, results suggest that the amount of ladino clover in the former was probably too small to have a measurable impact on the algebraic-mean NDF concentration in the mixed-species treatment. Ladino clover is a cool season-adapted legume, and cool-season legumes may not be satisfactory companion species in mixtures with tall-growing, warm-season species such as Johnsongrass because of differences in seedling vigor, optimum time of establishment, growth habit, relative maturation rates, and persistence (Posler et al., 1993).

Foliar concentration of ADF was 35.4% across forages and fertilizer-source treatments in the present study. Similarly, Adeli et al. (2005) observed a mean concentration of 39.2% ADF in Johnsongrass across multiple fertilizer-application rates, harvests and years. No fertilizer-source or forage treatment effects were observed for

ADF concentration in the present study, in agreement with Adeli et al. (2005) who reported that fertilizer source had no effect on ADF concentration in Johnsongrass. Within the Johnsongrass treatment, forage amended with commercial fertilizer had 5% higher ADF concentration than that amended with non-compacted broiler litter. However, this difference, while statistically significant, would not be expected to have a measurable effect on *in vivo* digestibility by the ruminant animal. Similarly, Johnsongrass fertilized with commercial fertilizer had 5% higher ADF concentration than Johnsongrass-clover forage, but this difference is probably too small to predict a measurable effect on digestibility in the live animal.

Across forages and fertilizer source-treatments, mean foliar concentration of hemicellulose in the present study was 29.7%. Similarly, Adeli et al. (2005) reported a mean value of 25.8% hemicellulose in Johnsongrass fertilized with swine effluent. Hemicellulose concentrations were not different between forage or among fertilizer-source treatments, in agreement with Adeli et al. (2005) who reported no fertilizer-source effect on hemicellulose concentration in stands of pure Johnsongrass. Temperate-zone legumes typically contain less hemicellulose than temperate-zone grasses (Van Soest, 1994); however, for reasons discussed previously, it is reasonable to assume that the proportion of clover in the mixed Johnsongrass-clover treatment was not sufficiently high to measurably affect its algebraic-mean hemicellulose concentration.

Foliar concentration of ADL was 3.2% across all harvests, years, forage and fertilizer-source treatments in the present study, and was not different between forage or among fertilizer-source treatments. Lignin is an indigestible polyphenolic compound that is covalently bound via ester and ethereal linkages with structural carbohydrates in the secondary cell wall. It is a major protractor of forage DM digestibility *in vivo* because of the negative effect of lignification on digestibility of NDF and ADF, of which ADL is a structural and analytical subset (Van Soest, 1994).

Relative feed value is calculated by reference to a digestible DM intake that has been adopted to standardize a mature legume forage (e.g., full-bloom alfalfa) containing 53% NDF and 41% ADF to an RFV of 100 (Linn and Martin, 1989). As such, it integrates intake and digestibility predicted from concentrations of NDF and ADF, respectively, into a single index that is used widely for describing forage nutritive quality (Lin et al., 2007). Mean RFV was 87.9 and was not different between Johnsongrass and Johnsongrass-clover forages or among fertilizer-source treatments. As such, nutritive quality of forage in the present study is estimated to be approximately 88% of that of a medium-quality alfalfa hay. By comparison, Franzluebbers et al. (2004) reported that Coastal Bermudagrass ranged in RFV from 85 to 100 in their study.

Foliar concentrations of Ca and P were not different between Johnsongrass and Johnsongrass-clover forages, or among fertilizer-source treatments. Wood et al. (1993) reported no difference in Ca concentrations of Bermudagrass plots fertilized with ammonium nitrate or broiler litter. In general, legumes have a much higher concentration of Ca in plant tissues than grasses (Whitehead et al., 1985). However, because Ca concentrations were not different between Johnsongrass and Johnsongrass-clover in the current study, this is additional evidence that the clover component of the mixed-species forage treatment may not have achieved its full growth potential. Foliar concentrations of P also did not differ between fertilizer sources or forage treatments. Previous studies have found that P concentrations are generally lower in legumes than grasses (Whitehead et al., 1985). Additionally, Wood et al. (1993) reported no difference in concentrations of P between Bermudagrass that had been fertilized with broiler litter or ammonium nitrate.

Potassium concentrations tended to be higher in forages amended with broiler litter than commercial fertilizer, in agreement with Wood et al. (1993) who reported 38% higher K concentration in Bermudagrass receiving broiler litter compared with ammonium nitrate. Also, Johnsongrass-clover forage contained 12% more foliar K than Johnsongrass, in agreement with Whitehead et al. (1985) who reported higher concentrations of foliar K in white clover than in common grasses. Also, using values from NRC (1996), only a 10% clover stand would have been necessary to achieve the observed K concentration in the clover-Johnsongrass forage mixture. This finding, in conjunction with the observed increase in concentration of CP in the Johnsongrass-clover treatment, suggests that there may have been a sufficient amount of clover to alter at least some of the elemental compositional characteristics of the mixed-species treatment, even though the clover component may not have achieved its full growth potential. A similar pattern was observed for foliar concentration of Mg, which was approximately 10% higher in Johnsongrass than Johnsongrass-clover forage, in agreement with Whitehead et al. (1985) who reported lower concentration of Mg in white clover than grasses. No differences were observed among fertilizer-source treatments in foliar Mg concentration. Previous studies have also shown no change in foliar Mg concentration of Bermudagrass fertilized with broiler litter or ammonium nitrate (Wood et al., 1993). Additionally, levels observed in the current study are within the maximum tolerable concentration (MTC) of 0.4% for beef cattle (NRC,1996).

One of the advantages of organic fertilizers over commercial fertilizer is their content of microelements that benefit plant productivity and nutrition of the grazing animal. However, it is important to monitor these for possible accumulation in soil and potential toxicity to livestock and humans (Ensminger and Olentine, 1978; Wood et al., 1993). Foliar concentrations of Al, Cu and Fe did not differ between forages or fertilizer-source treatments in the present study, in agreement with previous studies on Bermudagrass fertilized with broiler litter and ammonium nitrate (Wood et al., 1993). However, concentrations of both Al and Fe are above the MTC for beef cattle (NRC, 1996) of 1,000 mg/kg. Forages receiving commercial fertilizer had approximately 8% lower concentration of Zn than those receiving the broiler litter treatments, in contrast to findings by Wood et al. (1993) who reported no difference in foliar concentrations of Zn in Bermudagrass fertilized with either broiler litter or ammonium nitrate. Zinc is a component of several key metalloenzymes that is routinely added to poultry feed and may be excreted at relatively high concentrations in fecal material (Yi et al., 1996).

Broiler litter used for fertilization of forages in 2007 contained 62% DM, and 3.75% N, 1.4% P and 3.6% K on an air-equilibrated basis. In 2008, broiler litter contained 80% DM, and 3.4% N, 1.4% P and 3.7% K on an air-equilibrated basis. Application rates of broiler litter were based on soil-test P and were equivalent to 1,358 and 1,752 kg/ha in 2007 and 2008, respectively. This method of application required supplementation with ammonium nitrate to meet crop N requirements because experimental plots were still deficient by 16.3 and 19.0 kg N/ha in 2007 and 2008, respectively. To meet Alabama Cooperative Extension System recommendations for N, plots were supplemented with ammonium nitrate to achieve a total of 75 kg N/ha in both years.

Broiler litter is commonly land-applied based on soil-test recommendations for meeting crop N requirements (Read et al., 2006). Using this approach in the present study, broiler litter application would have needed to be 2,206 and 2,000 kg/ha in 2007 and 2008, respectively, representing a 62 and 14% increase over that actually applied in 2007 and 2008, respectively. These rates of application would have provided 40 and 28% more $P_2O_5$ equivalency in 2007 and 2008, respectively, than required based on soil test. While land application of broiler litter based on soil-test P limits the amount that can be land-applied compared with that based on crop requirement for N, it offers potential for preventing excessive P accumulation in soil.

# IMPLICATIONS

Results of this study indicate that pressure-compacted broiler litter supported productivity and nutritive quality of Johnsongrass comparable to that from non-compacted broiler litter. Also, broiler litter applied on the basis of soil-test P and supplemented with ammonium nitrate to meet crop N requirement supported productivity and nutritive quality of Johnsongrass comparable to that from commercial fertilizer. Pressure-compaction may enable economical transportation of broiler litter from areas of intensive poultry production to areas with low-fertility soils such as the Black Belt, providing limited-resource farmers with a cost-effective alternative to commercial fertilizer, while at the same reducing P loading onto soils in areas of intensive poultry production.

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