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Poultry Litter as a Sustainable Fertilizer for Stockpiled Tall Fescue during Winter Grazing in Middle Tennessee

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Abstract

Poultry litter has been used in crop production for many years and is particularly well suited for use as a plant nutrient source because of its high nutrient content compared with other manures. The objective of this research was to compare forage yield, forage nutritive value, beef cattle performance, and economics of stockpiled tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort] fertilized with commercial fertilizer or poultry litter. The research was conducted from October 2013 to April 2015 at the Middle Tennessee AgResearch and Education Center of the University of Tennessee, in Spring Hill. The experimental design was completely randomized with two treatments—ammonium nitrate used as commercial fertilizer or poultry litter—replicated three times. For the plant morphological components and forage nutritive value, there were no differences between N sources. However there was a year × N source interaction (P = 0.04) for crude protein (CP) concentration with CP values averaging 9.8% in 2014 and 10.8% in 2015. There were no differences between N sources for average daily gain (ADG), which was 1.19 lb/day in 2014 and 0.95 lb/day in 2015, or for stocking rate, which was 0.65 animal units (AU) per acre in 2014 and 0.49 AU/acre in 2015. In assessing N requirements of stockpiled tall fescue, producers should consider the cost of buying, transporting, and applying poultry litter compared with the cost of commercial fertilizer sources before making a decision to fertilize a particular pasture.

Nitrogen is the most common limiting factor for forage growth and quality in the southeastern USA. Increasing prices for N fertilizer as well as the associated externalities of fertilizer use have pressured livestock producers in Tennessee to evaluate alternatives to N fertilizer. Tall fescue is considered the primary forage base grazed by cow-calf producers in Tennessee and is an excellent forage crop due its high quality, production, and extended growing season. Generally, tall fescue pastures are fertilized in the spring and also in late summer for fall stockpiling. Stockpiled tall fescue is used because of its low cost compared with other feed sources, and it can maintain livestock for less than one-fourth the cost of hay (Bishop-Hurley and Kallenbach, 2001).

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Core Ideas

- Forage mass and quality of stockpiled fescue was not affected by N sources.
- Poultry litter application increased crude protein of stockpiled tall fescue.
- Fertilizer costs should be consider before its application to stockpiled fescue.

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Abbreviations: ADG, average daily gain; AU, animal unit; BW, body weight; CP, crude protein; IVDMD, in vitro dry matter digestibility; NDF, neutral detergent fiber; NDFD, NDF digestibility; TDN, total digestible nutrients.

Conversions: For unit conversions relevant to this article, see Table A.

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.454	pound, lb	kilogram, kg
0.405	acre	hectare, ha
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
2.54	inch	centimeter, cm (10–2 m)
0.304	foot, ft	meter, m
9.29×10^{-2}	square foot, sq ft	square meter, sq m
5/9 (°F – 32)	Fahrenheit, °F	Celsius, °C

Forage yield decreases during the fall and winter months in the southeastern USA, and one way to minimize this problem is to stockpile forage or accumulate forage mass during late summer and fall to extend the grazing season into the winter (Fribourg and Bell, 1984). The success of stockpiling depends on the accumulation period, choice of species, and nutrient management (Matches and Burns, 1995). Nitrogen fertilization prior to stockpiling forage can result in greater yield and nutritive value during the winter (Rayburn et al., 1979; Collins and Balasko, 1981).

With recent spikes and higher volatility in the price of commercial fertilizer, many producers have started considering alternative sources of N. Broiler production has increased in the southeastern USA in the last 15 years (Sleugh et al., 2006), making poultry litter more accessible and abundant for Southeast and Tennessee livestock and row-crop producers. Poultry litter has been used in crop production for many years to provide important nutrients to row crops and pastures (Simpson, 1991). Poultry litter is particularly well suited for use as a plant nutrient source because it has a higher nutrient content than other animal manures (Evers, 1998).

The advantages of poultry litter over commercial fertilizer include a supply of nutrients other than N; slower release of soluble N, thus reducing the risk of nutrient loss by leaching; improvement of soil structure; and potentially lower cost (Evers, 1998). Poultry litter contains many of the plant nutrients, suggesting it for use as a sustainable waste management (Tewolde et al., 2011). However, N availability and the dynamics of N mineralization from manures can be greatly influenced by environmental factors (biotic and abiotic) and so are not easily predictable for producers.

Poultry litter as a source of N can provide yields and nutritive value equal to or greater than those of forages fertilized with commercial fertilizer (Torbert et al., 1992). Teutsch et al. (2005) studied N-source effects on yield and quality of stockpiled tall fescue, but more information is needed about the relationship of yield and nutritive value to forage morphological composition and animal performance when grazing stockpiled tall fescue fertilized with poultry litter. Therefore, N fertilization strategies that include poultry litter should be investigated.

The objective of this research was to compare the forage yield, forage nutritive value, beef cattle performance, and economics of stockpiled tall fescue fertilized in autumn either with commercial fertilizer or poultry litter that will provide approximately 60 lb N/acre. Our hypothesis was that applying poultry litter as a N fertilizer source could be a sustainable alternative to commercial fertilizer for stockpiled tall fescue pastures. These results will inform Tennessee and Southeast livestock producers about optimal fertilizer decisions for stockpiling tall fescue.

Site Description, Treatments, Measurements, and Data Analysis

The research was conducted from October 2013 to April 2015 in six tall fescue pastures located at the Middle Tennessee AgResearch and Education Center of the University of Tennessee (35.68° N, 86.91°W, 810 ft altitude), in Spring Hill.

The soil was a Maury silt loam (a fine, mixed, active, mesic Typic Paleudalfs). The area had been managed as a well-fertilized pasture for the previous 10 years. Initial soil samples for the site were collected at a 6-inch depth in 2013 and 2014 and sent to the University of Tennessee Soil, Plant and Pest Center (Nashville) laboratory for analysis (Hanlon and Savoy, 2007) (Table 1). The two N-source treatments were initiated on 2 Oct. 2013 and 15 Sept. 2014. The experimental design was completely randomized with two treatments and three replications per treatment ($n = 6$). Treatments consisted of commercial fertilizer ammonium nitrate applied at a 60 lb N/acre and poultry litter applied at 1 ton/acre as a single application on an as-is basis at the same dates mentioned above. The commercial fertilizer

Table 1. Soil characteristics of the experimental site.

Year	Sampling date	pH	P	K	Ca	Mg
			—————	——— lb/acre	—————	
2013	09/23	6.0	91	132	1959	206
2014	09/12	6.0	93	148	2196	202

Table 2. Average nutrient concentration (dry-matter basis) of poultry litter used in this experiment.

pH	Moisture	NO_3 N	NH_4 N	N	P	K	Ca
	%	———	———	——— lb/ton	———	———	———
8.3	39.56	0.15	12.1	79.4	35.4	73.8	64.2

recommendation was the current tall fescue pasture recommendation for Middle Tennessee. The poultry litter rate was selected based on the plant-available N from the poultry litter used combined with the P levels contained in the soil (Table 1) in an attempt to avoid P toxicity. A composite sample was sent to the University of Arkansas Agriculture Diagnostic Laboratory (Fayetteville) for analysis (Peters et al., 2003) (Table 2).

Eighteen yearling heifers were identified each year, weighed, and randomly distributed in groups of three heifers per pasture under continuous stocking. All animals were weighed at the beginning and end of the study with an initial body weight (BW) of approximately 628 ± 21 lb in 2014 and 692 ± 17 lb in 2015. The difference between the final BW and initial BW was used to calculate BW gain by dividing the total days of the experimental period to calculate ADG. Stocking rate was calculated considering the total BW per acre and expressed as AU per acre, with AU corresponding to 1000 lb of BW. Pasture size was 3 acres with ungrazed forage accumulating from 2 Oct. 2013 and 15 Sept. 2014 until the beginning of grazing on 13 Jan. 2014 and 9 Jan. 2015.

During the 12-week grazing period each year, total aboveground dry matter available forage was measured weekly in each pasture with a calibrated rising plate meter (Sanderson et al., 2005). Forty points were measured at random across each pasture. To develop a regression equation for converting the rising plate meter reading to the total aboveground dry weight, each week several randomly placed 1 ft^2 sample areas were measured with the rising plate meter and then hand-clipped at ground level and dried to constant weight at 140°F.

Samples to characterize morphological composition and nutritive value of the forage canopy were collected from a 1-ft^2 area selected at random within each experimental unit on a weekly basis during the entire grazing period. Forage samples were collected above a 5-inch stubble height and separated into three categories: dead material, stem plus leaf sheath, and green lamina. All samples were dried at 140°F to constant weight. Herbage mass (lb dry matter /acre) was recorded for each component and summed to provide the total dry weight of each sample collected. Morphological components for each sample taken in each pasture were then combined and ground through a 1-mm screen in a shear mill (Thomas-Wiley Laboratory Mill Model 4, H. Thomas Co.) for laboratory analyses. Neutral detergent fiber (NDF), NDF digestibility (NDFD), crude protein (CP), in vitro dry matter digestibility (IVDMD), and total digestible nutrients (TDN) were predicted by means of near infrared spectroscopy (FOSS 5000, FOSS NIRSystems, Laurel, MD). Equations for the forage nutritive analyses were standardized and checked for accuracy with the 2013 Mixed Hay Equation developed by the NIRS Forage and Feed Consortium (NIRSC, Hillsboro, WI). Software used for NIRS analysis was Win ISI II supplied by Infrasoft International (State College, PA). The Global *H* statistical test compared the samples against the model and samples from distinct data sets within the database for accurate results, in which all forage samples fit the equation with the ($H < 3.0$) and are reported accordingly (Murray and Cowe, 2004).

Means for all variables analyzed were calculated for each replicate pasture. Data homogeneity, normality, and outlier values were verified. For the analyses of variance, the covariance structure for each variable was selected according to the Akaike information criterion. Weekly results of herbage mass and nutritive value were pooled into monthly averages. The following interactions effects were analyzed: year × month, year × fertilizer, and month × fertilizer. Animal performance variables were evaluated without month effects. The treatment effects were analyzed with the Tukey test ($P < 0.05$) utilizing the PROC MIXED of SAS (SAS Institute, 2008).

A producer decision to apply poultry litter or commercial fertilizer could affect forage quality and animal production, both of which also have impacts on the producer's net returns. That is, the producer also needs to consider the prices of fertilizer choice as well as the effect of the choice on forage quality and beef yield. For example, one of the fertilizers might cost more than the other but could result in forage and beef of higher yields, thus benefiting the producer for the additional cost of the fertilizer. Therefore, producers might want to consider using the fertilizer source (poultry litter or commercial fertilizer) that maximizes their profits.

Comparing the economics of using poultry litter against that of commercial fertilizer has several challenges. First, poultry litter contains several other nutrients beyond N fertilizer, which cannot be directly compared in this analysis. Also, the costs of poultry litter, application, and transportation vary by farm with distance from a poultry litter source, thus driving the economics of poultry litter use as a fertilizer. Therefore, the present study determined the break-even cost for buying, applying, and transporting poultry litter to estimate what a producer might be willing to pay to buy, apply, and transport 1 ton/acre instead of applying 60 lb/acre of commercial fertilizer N. The expected net returns were calculated for the two N fertilizer sources using a partial budgeting approach, which measures the changes in revenues and costs resulting from implementing a change in production practices (Kay et al., 2012). The producer's expected net returns for using commercial fertilizer was

$$E(NR_{CF}) = pE[y(N_{CF})] - r_{CF}N_{CF} - A_{CF},$$

where $E(NR_{CF})$ is the expected net return ($/acre) for using commercial fertilizer (CF); p is the price of beef ($/lb); $y(N_{CF})$ is beef yield (lb/acre), which is a function of the N fertilizer; r_{CF} is the price of the N fertilizer ($/acre); N_{CF} is the amount of N fertilizer applied (lb/acre); and A_{CF} is the cost of applying the N fertilizer ($/acre). The expected net returns for the using poultry litter was

$$E(NR_{PL}) = pE[y(N_{PL})] - Cost_{PL},$$

where $E(NR_{PL})$ is the expected net return ($/acre) for using poultry litter (PL), and $Cost_{PL}$ is the cost of buying, transporting, and applying the 1 ton/acre of poultry litter ($/acre).

The break-even cost of buying, applying, and transporting poultry litter was found by setting the net returns equal and solving for $Cost_{PL}$. This is expressed as

$$BE_{PL} = pE[y(N_{PL})] - pE[y(N_{CF})] + r_{CF}N_{CF} + A_{CF},$$

where BE_{PL} is the break-even cost of buying, transporting, and applying the 1 ton/ acre poultry litter ($/acre). If a producer could buy, transport, and apply poultry litter for less than the break-even cost, they would be better off using poultry litter rather than commercial fertilizer for stockpiling tall fescue.

The average beef yields (lb/acre) were from the experimental data in this study. The average price of beef was selected using the 10-year average price (from 2003 to 2012) for 600–800-lb heifer calves in Tennessee of $1.75/lb (USDA-NASS, 2013). The price of N from ammonium nitrate ranged from $0.3/lb in 2003 to $1/lb in 2013 (USDA-NASS, 2013). The producer's decision to use poultry litter rather than commercial fertilizer will depend on the price of N, and since there was such high variability in the price of N in recent years, we present results for the break-even cost (BE_{PL}) over a range of N fertilizer prices (r_{CF}). The application cost for N from ammonium nitrate was $7.69/acre, which were from the University of Tennessee Department of Agricultural and Resource Economics Custom Rate Survey (2013).

Weather Data, Available Forage, and Forage Nutritive Value

Weather data were evaluated for both years during the stockpiling period that preceded grazing (Fig. 1). In 2013, August–December rainfall averaged 3.4 inches per month, which was 20% below the 30-year average, and in 2014 it averaged 5 inches per month, which was 18% above the 30-year average. The mean air temperature from August to December was 0.5°F and 0.9°F above the 30-year average in 2013 and 2014. With the exception of the 2013 average rainfall being lower than adequate, rainfall in 2014 and temperature in both years were considered adequate for forage growth during the study period.

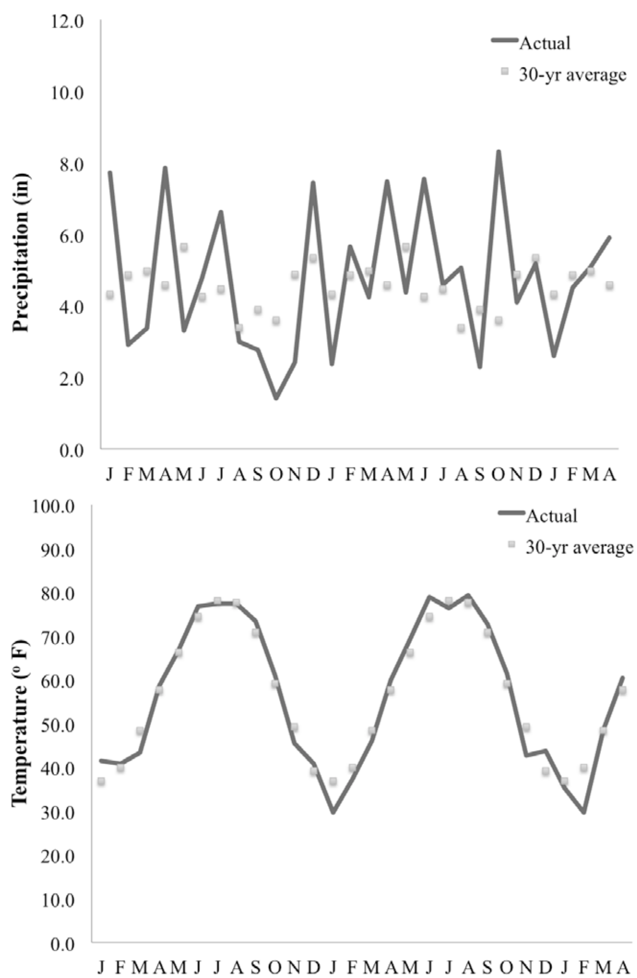

Fig. 1. Average monthly precipitation and temperatures in 2013, 2014, and 2015 and the 30-year average for Spring Hill, TN.

For all plant variables analyzed in this study (available forage variables and nutritive value variables), there were differences between years and between the three monthly grazing periods, with the exception of NDF, TDN, and IVDMD; NDFD differed only between monthly grazing periods only (Table 3). Total available forage was approximately 500 lb/acre greater in 2014, while leaf mass, dead material mass, and CP were approximately 8, 7, and 1% greater, respectively, in 2015. Available forage and dead material decreased by the end of the grazing period in March, as expected (Table 3). On the basis of weekly samplings, the percentage of leaves decreased by the second month, but increased by the end of the grazing period.

Forage nutritive value was not different among the monthly samples. Also, there was an interaction between year and month for mass of the morphological components and nutritive value variables. Stem mass was greater in February and March than in January, at the beginning of the experimental period (Table 3), along with a decrease in leaf mass. Early in the season, frequent defoliation is important to manage the rapid forage accumulation due to stem elongation (Nave et al., 2014).

Among plant morphological components and nutritive value variables, there were no differences between N sources (Table 3). Knowledge of pasture morphological composition is important to manage forage yield and nutritive value, and no changes occurred between inorganic fertilizer and poultry litter in a tall fescue pasture (Franzluebbers and Stuedemann, 2006). In the present study, no differences were found between N sources for the percentage of leaves, stems, and dead material in a stockpiled tall fescue pasture grazed during winter (Table 3). This is also important because cattle have the ability to select the uppermost vertical layers of forage, which have a higher CP concentration (Wilkinson et al., 1970). There was a year × source interaction effect for CP (Table 3). This could be attributed to the lower total precipitation in 2013. Nitrogen uptake can be greatly affected during years of inadequate precipitation (Colville et al., 1963). Nitrogen release rate was greatest during the first 60 days following poultry litter application (Pitta et al., 2012). During 2013, when poultry litter was applied, precipitation was below average during October and November following initial application (Fig. 1), which could have delayed mineralization of poultry-litter organic N. Teutsch et al. (2005) found no differences between N sources for tall fescue nutritive value. In the same study, no differences were observed between ammonium nitrate and poultry litter for tall fescue forage yield (Teutsch et al., 2005). Similarly in our study, N sources did not affect nutritive value or available forage in either year.

There was a N source × date interaction for available forage (Fig. 2). In both years, available forage was greater for the first 4 weeks and decreased in Weeks 5 and 6 however, available forage increased again toward the end of the grazing period. These trends were more evident in 2015 than in 2014. Despite variable weekly available forage, no differences between N sources were observed. Pastures fertilized with poultry litter showed less variation than those fertilized with commercial fertilizer (Fig. 2). But pastures fertilized with commercial fertilizer had somewhat less variation in CP than those fertilized with poultry litter (Fig. 3). In our study, stockpiled tall fescue fertilized with poultry litter resulted in more consistent available forage during the winter than commercial fertilizer. This was

Table 3. Available forage and nutritive value of stockpiled tall fescue as affected by year, month, and nitrogen source during winter grazing in Tennessee.

Plant variable	Year		Month			Source†		SEM	*P*-value					
	2014	2015	Jan.	Feb.	Mar.	CF	PL		Year	Month	Source	Year × month	Year × source	Month × source
						Available forage								
Total (lb/acre)	2200 a‡	1686 b	2162 c	1999 d	1713 e	2048	1821	69.6	<0.0001	0.007	0.08	0.30	0.32	0.59
Leaves (%)	14.2 b	22.0 a	30.0 c	10.3 e	18.5 d	17.3	14.5	13.7	0.0006	<0.0001	0.69	0.0008	0.56	0.73
Stem (%)	84.7 a	6.8 b	35.7 d	49.3 c	54.7 c	47.9	51.1	34.8	<0.0001	<0.0001	0.64	<0.0001	0.39	0.74
Dead (%)	1.13 b	7.12 a	34.3 c	40.3 c	26.8 d	34.8	34.4	31.8	<0.0001	0.0006	0.96	0.0002	0.96	0.92
						Nutritive value§								
CP (%)	9.78 b	10.8 a	9.73 d	9.78 d	11.4 c	10.5	10.2	2.44	0.003	<0.0001	0.43	<0.0001	0.04	0.34
NDF (%)	67.3	67.0	67.7	67.3	66.5	66.7	67.5	4.92	0.85	0.41	0.53	<0.0001	0.98	0.26
TDN (%)	59.3	60.1	59.1	59.4	60.6	60.1	59.1	4.28	0.54	0.12	0.46	<0.0001	0.54	0.31
IVDMD (%)	59.4	59.9	59.2	59.4	60.2	59.9	59.2	2.92	0.54	0.11	0.45	<0.0001	0.54	0.30
NDFD (%)	49.3	50.3	47.5 e	49.3 d	52.5 c	49.2	51.0	6.30	0.48	0.0006	0.17	<0.0001	0.90	0.45

† Fertilizer source: commercial fertilizer (CF) or poultry litter (PL).

‡ Year (a,b), month (c,d,e). Means without a common letter differ ($P < 0.05$).

§ CP, crude protein; NDF, neutral detergent fiber; TDN, total digestible nutrients; IVDMD, in vitro dry matter digestibility; NDFD, neutral detergent fiber digestibility.

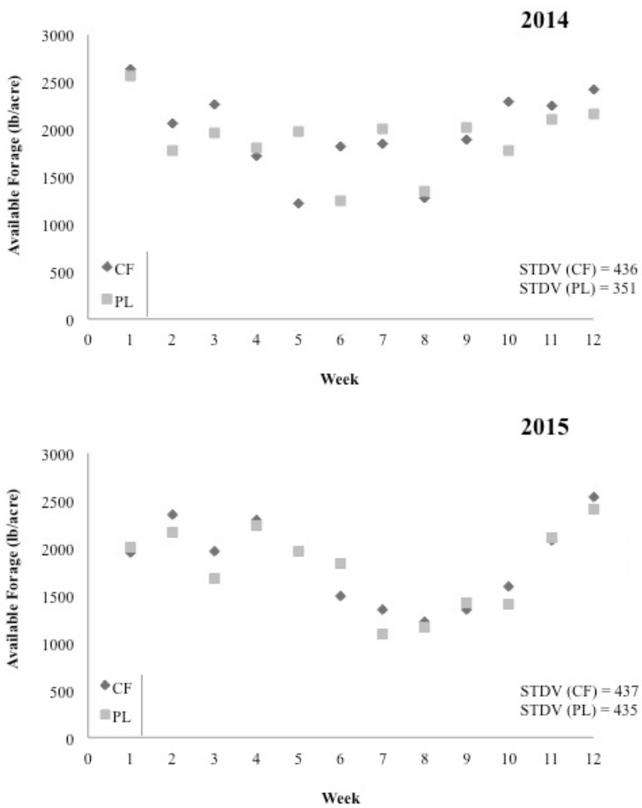

Fig. 2. Average weekly available forage and standard deviation (STDV) in 2014 and 2015 with commercial fertilizer (CF) and poultry litter (PL) for tall fescue during winter grazing in Middle Tennessee.

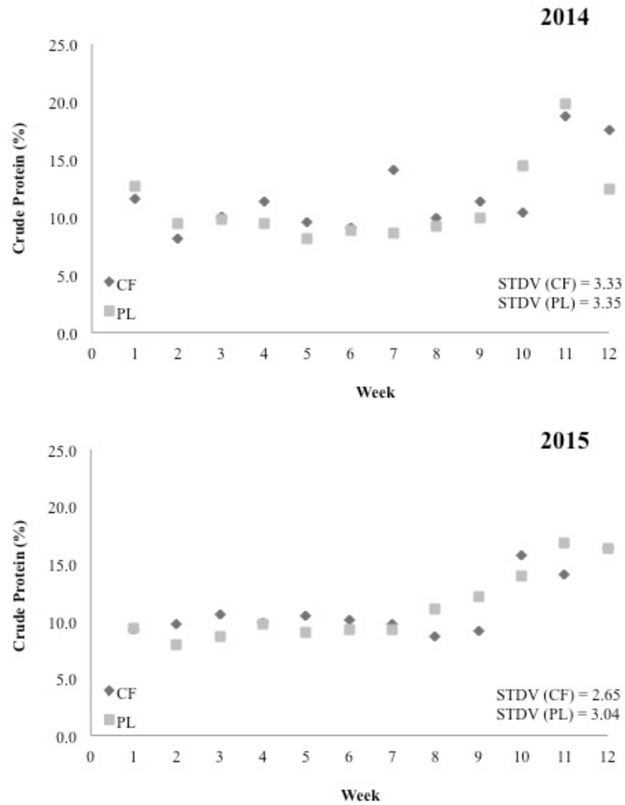

Fig. 3. Average weekly crude protein concentration and standard deviation (STDV) in 2014 and 2015 with commercial fertilizer (CF) and poultry litter (PL) for tall fescue during winter grazing in Middle Tennessee.

especially the case when precipitation was low. Also, in both years, poultry-litter-fertilized pastures had higher CP later in the season, when growing temperatures increased (Fig. 1 and 3). These results suggest that poultry litter can be considered an alternative N source for tall fescue pastures previously well fertilized with commercial fertilizers.

Animal Performance

The ADG of the heifers was 1.19 lb/day in 2014 and 0.95 lb/day in 2015 across 3 consecutive months of grazing during the winter (Table 4). This is in agreement with previous studies comparing the beef gain of unsupplemented calves grazing stockpiled tall fescue during winter (McClure et al., 1977; Poore and Green, 1999). Among all animal-related variables analyzed in this study, there were no differences between the N sources (Table 4). Although there is no previous research on stockpiled tall fescue, in northeast Georgia cattle that grazed bermudagrass pastures fertilized under two different strategies did not show differences in ADG between fertilization regimes in any season or if averaged annually (Franzluebbers and Stuedemann, 2006). Also in the same study, the stocking rate was also not different between fertilization regimes; however, the timing of nutrient availability to forage appeared

Table 4. Animal performance as affected by year and nitrogen source of stockpiled tall fescue during winter grazing in Tennessee.

	Year		Source†			*P*-value		
Animal variable‡	2014	2015	CF	PL	SEM	Year	Source	Year × source
ADG (lb/day)	1.19	0.95	1.12	1.01	0.04	0.20	0.61	0.89
BW gain (lb/acre)	92.8 a§	52.5 b	73.2	72.3	9.15	0.01	0.94	0.85
Stocking rate (AU/acre)	0.65 a	0.49 b	0.54	0.59	0.08	0.007	0.24	0.41

† Fertilizer source: commercial fertilizer (CF) or poultry litter (PL).

‡ ADG, average daily gain; BW, body weight; AU, animal unit (= 1000 lb of BW).

§ Means without a common letter differ ($P < 0.05$).

to be different for poultry litter than with inorganic fertilizers (Franzluebbers and Stuedemann, 2006).

In a study evaluating the impact of long-term application of poultry litter, elevated concentrations of P were observed in runoff from grasslands (Kingery et al., 1994). To reduce the accumulation of P in the soil and to maximize P uptake in poultry-litter-fertilized forages, management practices should focus on optimizing stem production since almost 60% of the total P in forages is located in stems (Pederson et al., 2002). When managed correctly, pasture poultry litter application may be a viable way to recycle nutrients such as N, P, and K in manure (Bolan et al., 2010) while aiding litter disposal problems and enhancing the physical, chemical, and biological fertility of soils (McGrath et al., 2009).

Economics

Producers need to consider the cost of buying, transporting, and applying poultry litter, as well as commercial fertilizer costs, before making a decision to fertilize stockpiled tall fescue (Fig. 4). Because the difference in average beef yields (per acre) for animals grazing stockpiled tall fescue fertilized with commercial fertilizer and poultry litter was small, the break-even cost was mainly a function of the cost of the commercial fertilizer. The break-even cost ranged from $24 to $60/acre as the price of N fertilizer increased from 0.3 to 0.9 $/lb. For example, if N from commercial fertilizer costs $0.60/lb, it would be more economical to apply 1 ton/acre of poultry litter instead of 60 lb/acre of commercial fertilizer N if it were possible to buy, transport, and apply poultry litter for less than $42/acre.

Conclusions

The available forage and nutritive value of stockpiled tall fescue during winter grazing was not affected by N sources; however, available forage showed less variation on weekly samples of forage fertilized the preceding autumn with poultry litter. Also, applying poultry litter resulted in a more consistent increase in

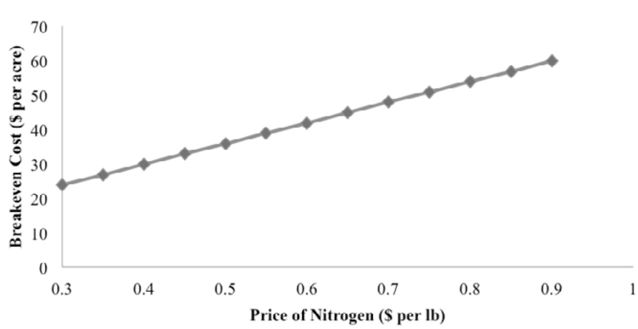

Fig. 4. Break-even cost of buying, transporting, and applying poultry litter versus commercial N fertilizer on stockpiled tall fescue.

CP during both years with increases in air temperature in late winter (March). There was also an interaction of year and N source on CP, suggesting the importance of adequate precipitation in the months following stockpiled tall fescue fertilization. It is important for the livestock producer to consider the costs of N fertilizers before deciding the application source of N.

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References

Bishop-Hurley, G.J., and R.L. Kallenbach. 2001. The economics of grazing beef cows during winter. Proc. Am. Forage Grassland Counc. 10: 274.

Bolan, N.S., A.A. Szogi, T. Chuasavathi, B. Seshadri, M.J. Rothrock, Jr., and P. Panneerselvam. 2010. Uses and management of poultry litter. Worlds Poult. Sci. J. 66:673–698. doi:10.1017/S0043933910000656

Collins, M., and J.A. Balasko. 1981. Effects of N fertilization and cutting schedules on stockpiled tall fescue. II. Forage quality. Agron. J. 73:821–826. doi:10.2134/agronj1981.00021962007300050018x

Colville, W.L., L. Chesnin, and D.P. McGill. 1963. Effect of precipitation and long term nitrogen fertilization on nitrogen uptake, crude protein content and yield of bromegrass forage. Agron. J. 55:215–218. doi:10.2134/agronj1963.00021962005500030002x

Evers, G.W. 1998. Comparison of broiler poultry litter and commercial fertilizer for coastal bermudagrass production in the Southeastern US. J. Sustainable Agric. 12:55–77. doi:10.1300/J064v12n04_06

Franzluebbers, A.J., and J.A. Stuedemann. 2006. Pasture and cattle responses to fertilization and endophyte association in the southern Piedmont, USA. Agric. Ecosyst. Environ. 114:217–225. doi:10.1016/j.agee.2005.10.003

Fribourg, H.A., and K.W. Bell. 1984. Yield and composition of tall fescue stockpiled for different periods. Agron. J. 76:929–934. doi:10.2134/agronj1984.00021962007600060016x

Hanlon, E.A., and H.J. Savoy. 2007. Procedures used by state soil testing laboratories in the southern region of the United States. Southern Cooperative Series Bull. 190-D. Clemson Exp. Stn., Clemson, SC.

Kay, R.D., W.M. Edwards, and P.A. Duffy. 2012. Farm management. 7th ed. McGraw-Hill, New York.

Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. Williams, and G.L. Mullins. 1994. Impact of long-term land application of broiler litter on environmentally related soil properties. J. Environ. Qual. 23:139–147. doi:10.2134/jeq1994.00472425002300010022x

Matches, A.G., and J.C. Burns. 1995. Systems of grazing management. In: R.F. Barnes et al., editors, The science of grassland agriculture. Vol. 2 of Forages. 5th ed. Iowa State Univ. Press, Ames. p. 179–192.

McClure, W.H., J.P. Fontenot, and H.J. Gerken, Jr. 1977. Stockpiled fescue for wintering beef calves. Res. Division Rep. 172. Virginia Polytechnic Inst. and State Univ., Blacksburg. p. 79–81.

McGrath, S., R.O. Magure, B.F. Tacy, and J.H. Kike. 2009. Improving soil nutrition with poultry litter application in low input forage systems. Agron. J. 102:48–54. doi:10.2134/agronj2009.0198

Murray, I., and I. Cowe. 2004. Sample preparation. In: C.A. Roberts et al., editors, Near infrared spectroscopy in agriculture. ASA, CSSA, SSSA, Madison, WI. p. 75–115.

Nave, R.L.G., R.M. Sulc, D.J. Barker, and N. St-Pierre. 2014. Changes in forage nutritive value among vertical strata of a cool-season grass canopy. Crop Sci. 54:2837–2845. doi:10.2135/cropsci2014.01.0018

Pitta, C.S.R., P.F. Adami, A. Pelissari, T.S. Assmann, M.F. Franchin, L.C. Cassol, and L.R. Sartor. 2012. Year-round poultry litter decomposition and N, P, K and Ca release. Rev. Bras. Cienc. Solo 36:1043–1053. doi:10.1590/S0100-06832012000300034

Pederson, G.A., G.E. Brink, and T.E. Fairbrother. 2002. Nutrient uptake in plant parts of sixteen forages fertilized with poultry litter. Agron. J. 94:895–904. doi:10.2134/agronj2002.8950

Peters, J., S.M. Combs, B. Hoskins, J. Jarman, J.L. Kovar, M.E. Watson, A.M. Wolf, and N. Wolf. 2003. Recommended methods of manure analysis. Univ. of Wisconsin Coop. Ext., Madison.

Poore, M.H., and J.T. Green. 1999. Influence of supplementing growing heifers grazing stockpiled fescue with a pressed block containing whole cottonseed. Dep. of Anim. Sci. Rep. 248. North Carolina State Univ., Raleigh. p. 24–26.

Rayburn, E.B., R.E. Blaser, and D.D. Wolf. 1979. Winter tall fescue and quality with different accumulation periods and N rates. Agron. J. 71:959–963. doi:10.2134/agronj1979.00021962007100060017x

Sanderson, M.A., K.J. Soder, L.D. Muller, K.D. Klement, R.H. Skinner, and S.C. Goslee. 2005. Forage mixture productivity and botanical composition in pastures grazed by dairy cattle. Agron. J. 97:1465–1471. doi:10.2134/agronj2005.0032

SAS Institute. 2008. SAS/STAT 9.2 user's guide. SAS Inst., Cary, NC.

Simpson, T.W. 1991. Agronomic use of poultry litter waste. Poult. Sci. 70:1126–1131. doi:10.3382/ps.0701126

Sleugh, B.B., R.A. Gilfillen, W.T. Willian, and H.D. Henderson. 2006. Nutritive value and nutrient uptake of sorghum-sundangrass under different broiler litter fertility programs. Agron. J. 98:1594–1599. doi:10.2134/agronj2005.0286

Teutsch, C.D., J.H. Fike, G.E. Groover, and S. Aref. 2005. Nitrogen rate and source effects on the yield and nutritive value of tall fescue stockpiled for winter grazing. Forage Grazinglands. doi:10.1094/FG-2005-1220-01-RS.

Tewolde, H., A. Adeli, K.R. Sistani, and D.E. Rowe. 2011. Mineral nutrition of cotton fertilized with poultry litter or ammonium nitrate. Agron. J. 103:1704–1711. doi:10.2134/agronj2011.0174

Torbert, H.A., C.W. Wood, and D.P. Delaney. 1992. Highlights of agricultural research (Alabama Agric. Exp. Stn.) 39 (3):12–13.

University of Tennessee Department of Agricultural and Resource Economics. 2013. Custom rate survey. Available at http://economics.ag.utk.edu/extension/pubs/CustomRates2013-rev.pdf (accessed 5 June 2016).

USDA National Agricultural Statistics Service (USDA-NASS). 2013. Quik stats. http://quickstats.nass.usda.gov/ (accessed 17 June 2016).

Wilkinson, S.R., W.E. Adams, and W.A. Jackson. 1970. Chemical composition and in vitro digestibility of vertical layers of coastal bermudagrass (*Cynodon dactylon* L.). Agron. J. 62:39–43. doi:10.2134/agronj1970.00021962006200010013x