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Pasture and cattle responses to fertilization and endophyte association in the southern Piedmont, USA

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Abstract

A 3-year experiment was conducted to determine pasture and cattle responses to tall fescue–endophyte association (free, novel, and wild endophyte associated with 'Jesup' cultivar) and fertilization source (inorganic and broiler litter). Fertilization source had only minor or no effects on botanical composition, forage mass, cattle stocking rate, and yearly cattle performance and productivity. However, cattle performance and production were greater with broiler litter than with inorganic fertilization during summer, but lower in autumn and winter, suggesting a difference in timing of nutrient availability to forage due to mineralization of organic nutrients in broiler litter. Pastures with wild endophyte association either had higher forage mass during some periods or were able to carry more cattle than other endophyte associations. Cattle performance was lower with wild than with other endophyte associations at all times of the year, except in summer. Cattle gain in winter was not different among endophyte associations (64 kg ha^{-1}; $p = 0.43$), was lower in spring with wild endophyte than with other endophyte associations (244 kg ha^{-1} versus 302 kg ha^{-1}; $p = 0.04$), was higher in summer with wild endophyte (147 kg ha^{-1} versus 117 kg ha^{-1}; $p < 0.001$), and was lower in autumn with wild endophyte (97 kg ha^{-1} versus 129 kg ha^{-1}; $p = 0.10$). Seasonal differences in pasture responses to fertilization and endophyte association suggested that management options could be developed to avoid or limit toxic cattle responses to wild endophyte.

Keywords: Botanical composition; Broiler litter; Cattle gain; Endophyte free; Novel endophyte; Wild endophyte

1. Introduction

Tall fescue (*Festuca arundinacea* Schreb.) is a widely disseminated, perennial, cool-season grass grown around the world. In the USA alone (mostly in the eastern half of the USA), it is grown on ca. 14 Mha of land (Buckner et al., 1979). Its geographical distribution surpasses many other cool-season grasses available to producers in this country. Therefore, it is considered the most important perennial, cool-season grass in the southeastern USA. It withstands grazing pressure by foraging cattle and persists better than other cool-season perennial forages, making it an excellent choice for keeping pastures productive for years. In addition to its desirable cool-season attributes, it is productive when moisture is available during the summer, but more importantly, survives the hot, drought-prone conditions common during the summer.

One reason for the superior persistence of tall fescue is likely related to a mutualistic association with a fungal endophyte (*Neotyphodium coenophialum* Glenn, Bacon & Hanlin) first reported by Bacon et al. (1977). The fungus resides in the above-ground portions of susceptible grasses, where it produces various alkaloids that have been shown to be toxic when consumed in large quantities by grazing cattle, sheep, and horses (Stuedemann and Hoveland, 1988). In addition to the negative effects on grazing cattle, toxic alkaloids produced in leaf tissue of endophyte-infected forage can deter herbivorous insects (Prestidge et al., 1982; Latch, 1993; Rowan and Latch, 1994) and other pests such as pathogenic fungi, viruses, and root-feeding nematodes (Latch, 1997), leading to greater persistence of endophyte-infected

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forage. Endophyte infection can also enhance drought resistance of forage (Bouton et al., 1993; West et al., 1993), which could affect water utilization from the soil profile.

Recently, research into endophyte associations has led to the development of a novel strain of fungal endophyte that does not induce the production of toxic ergot alkaloids in leaf tissue, but retains the endophyte to help maintain persistence (Bouton et al., 2002). A distinction can now be made between wild endophyte association (occurring naturally with high ergot alkaloid production) and novel endophyhte association (selected fungus with little or no ergot alkaloid production). Long-term data on the persistence of tall fescue stands with novel endophyte are not yet available, but short-term evaluations have suggested greater persistence than endophyte-free stands (Bouton et al., 2002). Making a choice among high wild-type endophyte infection with poor animal performance (Stuedemann and Hoveland, 1988; Schmidt and Osborn, 1993), endophyte-free tall fescue with poor plant persistence (Read and Camp, 1986; Bouton et al., 1993; Franzluebbers and Stuedemann, 2005), or novel-endophyte-infected tall fescue that has relatively high current seed cost and uncertain persistence is not easy for animal producers, because of the lack of data to quantify long-term production, ecological, and economic impacts of these choices.

In tall fescue pastures, there are a few key management factors that producers can control, which can significantly affect the balance between productivity and environmental quality. These factors include:

- type of tall fescue cultivar and/or endophyte association;
- interseeded crop to increase productivity;
- fertilizer quantity, timing, and source;
- grazing pressure and harvest management.

The objective of this study was to determine the effect of the factorial arrangement of fertilization source and tall fescue–endophyte association on pasture and cattle responses during the first 3 years of an intended long-term study. Botanical composition of pastures is an important variable that controls forage productivity and quality and cattle production. Nutrients derived from inorganic or organic sources could affect forage and cattle productivity in many ways, including seasonal and total availability of macronutrients and secondary nutrients, and potential interaction with endophyte-produced metabolites of forage that could alter cattle responses (Malinowski and Belesky, 2000). Although information is abundant on cattle performance and production in wild-type and endophyte-free associations, little current information is available to assess the effect of novel endophyte association on forage and cattle production.

2. Materials and methods

The field experiment was located on a 20 ha tract of typical southern Piedmont landscape operated by the J. Phil Campbell Sr. Natural Resource Conservation Center near Watkinsville, GA (33°52′N, 83°25′W). Slope varied from 0 to 10%. Long-term mean annual precipitation was 1250 mm and temperature was 16.5 °C. Soils were sandy loam to sandy clay loam (clayey, kaolinitic, thermic Typic Kanhapludults) composed of 80% Cecil, 12% Pacolet, and 8% Appling.

The site was developed for this experiment during 1998–2001 by establishing a set of 14 experimental paddocks (1.00 ± 0.05 ha each) with ≈0.4 m high and 1 m wide soil berms along the edge of each experimental unit. Good stands of all tall fescue ('Jesup')–endophyte associations were obtained by spring of 2002 following attempts to seed pastures with no-tillage planting during several previous autumns (precipitation during 1999–2001 was only $76 \pm 8\%$ of yearly normal). Land was sprayed with glyphosate (1.0–1.9 L a.i. ha^{-1}) and/or paraquat (1.3 L a.i. ha^{-1}) prior to seeding. Tall fescue was drilled in 20-cm-wide rows at a rate of 20–30 kg ha^{-1} in autumn of each year. Graze-on [2,4-D (0.9–1.4 L a.i. ha^{-1}) + picloram (0.2–0.4 L a.i. ha^{-1})] was sprayed onto pastures in spring of 2001 to control broadleaves with no further chemical weed control after successful stand establishment. Dolomitic limestone at 2.2 Mg ha^{-1} was spread on all paddocks in March 2002.

The experimental design was a randomized arrangement of seven treatments in two blocks. Six of the seven treatments were grazed by yearling Angus heifers whenever sufficient forage was available and the remaining treatment was cut for hay. The six grazed treatments were a factorial combination of three tall fescue–endophyte associations and two fertilization strategies. Tall fescue–endophyte associations were: (1) endophyte-free Jesup tall fescue (Free), (2) Jesup tall fescue infected with a novel endophyte that produces low levels of ergot alkaloids, marketed as Max-Q by Pennington Seed[1] (Novel), and (3) Jesup tall fescue infected with a naturalized wild strain of fungus that produces high levels of ergot alkaloids (Wild). Fertilization strategies were: (1) inorganic fertilizer applied at 180–45–90 kg N–P_2O_5–K_2O ha^{-1} $year^{-1}$ split during early spring and early autumn and (2) broiler litter applied twice yearly in spring and autumn to supply similar available N as with inorganic fertilizer (we assumed 67% of applied N would be available during the first year). Actual nutrient application varied (Table 1) due to spreading with commercial equipment and variability of nutrient concentration in broiler-house floor litter. All broiler litter was purchased from the same chicken grower, who spread litter onto paddocks with a truck-type spreader.

Each paddock contained a 2 m × 4 m corrugated-metal shade, a non-freezing water tank, and a mineral feeder positioned in a 20 m line to accommodate two criteria: (1)

[1] Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

Table 1
Nutrients applied to pastures (kg ha^{-1})

Characteristic	2002		2003		2004	
	Spring	Autumn	Spring	Autumn	Spring	Autumn
Inorganic fertilization						
Nitrogen	87	95	94	92	81	90
Phosphorus	19	0	21	0	21	0
Potassium	72	0	78	0	49	0
Broiler litter fertilization						
Dry matter	–	2325	2321	2787	2262	2295
Carbon	–	1168	1230	1049	1161	631
Total nitrogen	87	92	106	109	127	80
Ammonium-N	–	18	23	15	11	7
Nitrate-N	–	0.6	0.4	0.5	0.3	0.1
Phosphorus	19	39	41	41	26	23
Potassium	72	82	86	87	54	51
Calcium	–	45	51	58	35	31
Magnesium	–	11	14	13	9	8

high point of the paddock and (2) maximum distance from a water-runoff flume positioned at the lowest point of each paddock. Paddocks were arranged on either side of a central roadway, which was connected to a covered animal handling facility.

Grazing of paddocks was initiated in April 2002. Grazing was with a variable stocking rate based on a pool of weaned Angus heifers made available each year in October. Maximum herd size was 66 animals in October 2001, 62 in 2002, 59 in 2003, and 50 in 2004. Stocking of pastures was adjusted every 28 d to achieve similar forage mass among all paddocks. However, forage mass varied within the year due to limited number of animals that allowed occasional excess growth. Minimum forage mass was targeted at 1 Mg ha^{-1}. Once minimum forage mass was reached for the majority of experimental units, animals were removed from all paddocks, and returned only when sufficient forage became available for extended grazing. Off the paddocks, cattle grazed a nearby pool area of endophyte-free tall fescue supplemented with hay whenever necessary.

The hayed treatment was Jesup tall fescue with novel endophyte fertilized inorganically at the same rate as grazed paddocks. Hay was cut and baled with commercial equipment whenever sufficient forage was available ($>$1 Mg ha^{-1}).

Botanical composition of pastures was determined in May 2002, July 2003, and July 2004 by visual assessment of percent basal cover from five typical components [i.e., tall fescue, annual grass, broadleaves, common bermudagrass ((*Cynodon dactylon* (L.) Pers.), and bare ground]. Visual assessments were made by the same experienced technician from 30 equally distributed locations of 0.25 m^2 areas within each paddock. Ground cover was estimated to the nearest 5% of a component. Annual grass was composed primarily of Italian ryegrass (*Lolium multiflorum* Lam.) and crabgrass (*Digitaria* spp. Haller). Broadleaves were composed of henbit (*Lamium amplexicaule* L.), chickweed (*Cerastium nutans* Raf.), and other minor weeds.

Forage mass was determined a few days prior to scheduled cattle restocking dates using a calibrated falling-plate meter (0.8 m^2 area) at 30 equally distributed locations within each paddock. Calibrations of disk height against dry forage mass within the same area were made at different times of the year to account for plant architectural changes.

Tall fescue leaves were sampled in early May 2003 by plucking forage from $>$30 locations throughout a paddock. Ergot alkaloid concentration of forage was determined with an enzyme-linked immonosorbance assay (Hiatt and Hill, 1999). Ergot alkaloid concentration averaged across fertilization source and replications was 439 ng g^{-1} (novel) = 681 ng g^{-1} (free) $<$ 1565 ng g^{-1} (wild).

Cattle production and performance were determined from periodic weighing of heifers, which were 8 months old in October and weighed 185 ± 7 kg $head^{-1}$. Cattle were dewormed with pour-on eprinomectin (10 ml 100 kg^{-1} body weight) and albendazole suspension drench (8.8 ml 100 kg^{-1} body weight) and kept in drylot for 3 d prior to distribution onto experiment paddocks each year in spring and autumn (18 April and 27 September 2002, 10 March and 14 November 2003, 15 March and 15 October 2004). Cattle shrunk weight at the beginning and end of each grazing period was determined by not offering water for 16 h, herding into the handling facility, and weighing of tagged animals on a digital balance in a cattle chute. Live-weight gain was calculated as the difference in initial and final weight of all cattle placed on a paddock during a grazing period. Typical grazing periods were for 28 d, but periods ranged from 14 to 33 d to accommodate weather and work schedules. Average daily gain was calculated from live-weight gain divided by the number of cattle and number of grazing days in a period. Stocking rate was calculated as the number of cattle on pasture adjusted to the total time available in a season, not just the time on paddocks.

Since stocking of pastures with cattle was expected to occur throughout the year, we divided the year into four seasons to account for periods of major difference in precipitation and temperature, which would affect pasture growth and development. Some 28-d grazing periods overlapped seasonal cutoff dates (i.e., 21–22 March, June, September, and December), so proportional weighting of that period was assigned to both seasons. Stocking of pastures during a season was not continuous during the 3-year evaluation period, because of either low forage mass sometime from winter to summer or changing of herds in autumn.

Response variables were analyzed for variance within individual and across evaluation periods using the general linear models procedure of SAS. Multiple observations within a period were pooled into a single mean or cumulative observation, such that model variation was always partitioned into blocking (1d.f.), fertilization (1d.f.), tall fescue–endophyte association (2d.f.), interaction of fertilization and tall fescue–endophyte association (2d.f.), and error (5d.f.). Means were separated by least significant difference at $p < 0.1$. Forage mass across all sampling events was compared with a paired t-test, because it could not be summed within a season or across the year due to both growth and consumption.

3. Results and discussion

Averaged across the 3 years of this experiment, climatic conditions were near normal (Table 2). However, significant variation in precipitation occurred among years, with 2002 being driest (1150 mm), 2003 being wettest (1410 mm), and 2004 being intermediate (1300 mm). Some of the summer and autumn months in 2003 and 2004 had very high precipitation due to hurricanes (e.g., 316 mm in July 2003 and 298 mm in September 2004). Summer had the highest mean precipitation compared with other seasons (Table 2) and also the highest coefficient of variation among 10-d intervals (117%), followed by autumn (100%), spring (85%), and winter (69%).

The percentage of time that cattle grazed paddocks varied substantially during the year due to forage mass availability, which was controlled by climatic conditions. Time of grazing was greatest in spring (85%) and autumn (65%). Although high temperature can limit tall fescue growth, it is the lack of precipitation combined with high temperature that limits its growth. Grazing time was 67% in summer, which was relatively high due to high precipitation in 2003. Grazing time was lowest in winter (26%) due to low temperature that limited forage growth.

The interaction of fertilization with tall fescue–endophyte association was rarely significant for most pasture response variables on individual sampling dates and never on a seasonal or yearly basis. Therefore, only main effects of fertilization and tall fescue–endophyte association have been presented in the following.

Table 2
Climatic conditions, cattle productivity and performance, and pasture stocking conditions averaged across tall fescue–endophyte associations as affected by season and fertilization regime

Fertilization regime	Season				Yearly
	Winter	Spring	Summer	Autumn	
Climatic conditions					
Temperature (°C)	7.9	19.4	25.2	13.8	16.6
Precipitation (mm)	295	291	364	336	1286
Total stocking weight (Mg ha^{-1})					
Inorganic	0.78	1.19	1.14	0.72	1.00
Broiler litter	0.71	1.09	1.12	0.74	0.96
L.S.D. ($p = 0.1$)	0.11	0.15	0.12	0.06	0.09
Stocking rate (head ha^{-1})[a]					
Inorganic	0.9	3.9	2.3	2.6	2.4
Broiler litter	0.8	3.5	2.2	2.7	2.3
L.S.D. ($p = 0.1$)	0.2	0.5	0.3	0.2	0.3
Live-weight gain (kg ha^{-1})					
Inorganic	74	293	117	129	613
Broiler litter	55	273	137	107	572
L.S.D. ($p = 0.1$)	9*	41	3*	30	70
Average daily gain (kg head^{-1} d^{-1})					
Inorganic	0.87	0.86	0.59	0.61	0.72
Broiler litter	0.72	0.87	0.68	0.48	0.70
L.S.D. ($p = 0.1$)	0.11*	0.03	0.06*	0.08*	0.04

[a] Adjusted to total time available, not just the time on paddocks.
* Following L.S.D. value indicates significance among means.

3.1. Effect of fertilization

Botanical composition of pastures was dominated by tall fescue as intended, but was little affected by fertilization regime (Table 3). Basal ground cover of tall fescue was not different between fertilization regimes during the first 2 years, but was lower under broiler litter than under inorganic fertilization in 2004. No other significant changes in botanical composition occurred in response to fertilization regime. The timing of visual assessments among years varied somewhat, and this may have caused some shifts in actual values among years. Annual ryegrass was a large component of pastures initially, but animal grazing and development of tall fescue sod limited this component with time through competition.

Forage mass was similar between fertilization regimes on most sampling dates, but was lower under broiler litter than under inorganic fertilization from November 2002 to March 2003, during May and June 2003, in March 2004, and in January 2005 (data not shown). These differences occurred on nine of the 32 sampling dates. On only one date in November 2003 was forage mass greater under broiler litter than under inorganic fertilization. From paired *t*-tests across sampling dates, forage mass was lower ($p < 0.01$) under broiler litter (1.40 ± 0.42 Mg ha^{-1}) than under inorganic fertilization (1.47 ± 0.44 Mg ha^{-1}).

Cattle stocking weight was not different between fertilization regimes in any season, nor averaged annually (Table 2). Stocking weight was lowest in autumn and winter due to generally lower forage mass following summer grazing and smaller calves that were renewed in October of each year. Stocking rate adjusted to the total time available within a season was also not different between fertilization regimes at any time. Stocking rate was lowest in winter due to limited grazing time and highest in spring when growth of tall fescue was most rapid.

Cumulative yearly cattle live-weight gain was not different between fertilization regimes (Table 2). However, live-weight gain was lower under broiler litter than under inorganic fertilization in winter and higher in summer. Timing of nutrient availability to forage, and its subsequent consumption by cattle, appeared to be significantly different with broiler litter compared with inorganic fertilization. High temperature and sufficient soil moisture in summer may have allowed significant mineralization of organically bound nutrients in broiler litter to increase forage production and/or quality, despite application in autumn and early spring. Broiler litter was equally effective as inorganic fertilization in producing sufficient forage for cattle gain during spring and autumn, when live-weight gain was greatest (i.e., 68% of yearly total).

Average daily gain responded to fertilization regime in a similar manner as cattle live-weight gain (Table 2). Average daily gain was greater under broiler litter than under inorganic fertilization in summer and lower in autumn and winter. Averaged across the year, daily gain was equivalent between fertilization regimes.

3.2. Effect of tall fescue–endophyte association

Botanical composition of pastures became progressively more dominated by tall fescue in all three tall fescue–endophyte associations, but achieved a higher level of tall fescue dominance during the third year with either endophyte than without (Table 3). Initially, annual ryegrass was a significant component in the novel endophyte association, but declined dramatically with time. During the third year, annual grass remained a significant component only in the endophyte-free association. Broadleaf weeds were not a significant component in any tall fescue–endophyte association in any year, due to initial broadleaf weed control in 2002. Density of living ground

Table 3
Percent ground cover of pastures evaluated in May 2002, July 2003, and July 2004

Treatment	Tall fescue			Annual grass			Broadleaves			Bare ground		
	2002	2003	2004	2002	2003	2004	2002	2003	2004	2002	2003	2004
Effect of fertilization												
Inorganic	49	84	79	26	10	3	0	1	1	25	6	17
Broiler litter	47	78	71	27	15	7	1	3	2	22	3	16
L.S.D. ($p = 0.1$)	10	9	3*	15	7	4	3	4	3	11	4	9
Effect of tall fescue–endophyte association												
Free	50	73	70	25	22	13	0	1	1	25	4	17
Novel	34	82	79	38	7	0	1	4	3	26	7	18
Wild	59	88	79	17	9	1	0	0	0	18	3	16
L.S.D. ($p = 0.1$)	13*	11*	4*	19*	9*	5*	3	5	3	13	4	10
Effect of harvest management of novel endophyte fertilized inorganically												
Hayed	34	91	42	5	3	12	9	4	0	52	2	46
Grazed	36	87	82	35	4	0	1	0	1	28	8	17
L.S.D. ($p = 0.1$)	18	15	6*	26*	12	8*	5*	7	5	18*	6*	15*

* Following L.S.D. value indicates significance among means.

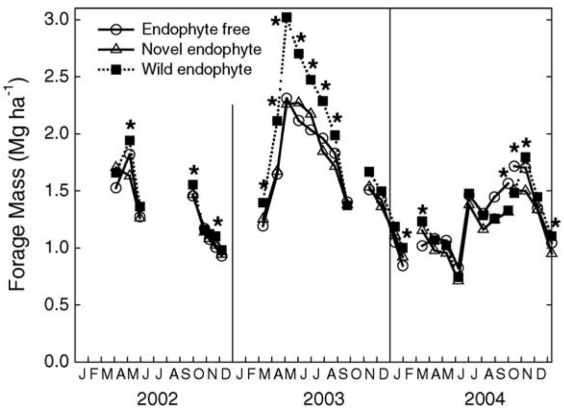

Fig. 1. Forage mass as affected by tall fescue–endophyte association during sampling events from 2002 to 2004. Asterisk above group of symbols indicates significance between at least two means at $p < 0.1$.

cover was not affected by tall fescue–endophyte association in any year, as reflected by no treatment difference in bare ground. Bare ground varied among years and was probably a reflection of rainfall prior to sampling that controlled forage mass. Forage mass at the time of estimation of botanical composition in May 2002 and July 2004 was $\leq$1.5 Mg ha^{-1} and in July 2003 was >2.0 Mg ha^{-1} (Fig. 1). Greater percent ground cover as tall fescue under novel endophyte than endophyte-free association in 2004 (Table 3) indicated potentially greater persistence, similar to that shown by Bouton et al. (2002) and a review of short-term studies reported in Gunter and Beck (2004). Despite our consistent short-term results with literature sources, longer term evaluations of tall fescue persistence are still needed.

Forage mass was greater with wild than with other endophyte associations on 14 of the 32 measurement dates during the 3-year period (Fig. 1). The longest stretch of time that this effect occurred was from March 2003 to the end of August 2003. Another divergence in forage mass occurred in autumn of 2004, when greater forage mass was obtained in endophyte-free than with novel endophyte association. Forage mass was intended to be equivalent among treatments on any particular date, but may not have been due to a number of factors related to the balance between forage growth and consumption by grazing cattle. The greater forage mass with wild than with other endophyte associations was likely due to lower forage consumption by cattle that were being negatively affected by toxins produced in the wild endophyte association. Matching of forage mass with projected forage growth during a 28-d period combined with a relatively small number of animals on a paddock presented us with some difficulty in equalizing forage among treatments in the short-term, but in the long-term this imbalance was accounted for in altered stocking rate and live-weight gain. From paired t-tests across the 32 sampling dates, forage mass in the endophyte-free association (1.41 ± 0.38 Mg ha^{-1}) was greater ($p = 0.07$) than in the novel endophyte association (1.37 ± 0.39 Mg ha^{-1}) and both lower ($p < 0.01$) than in the wild endophyte association (1.53 ± 0.53 Mg ha^{-1}).

Cattle stocking weight was greater in pastures with wild than with other endophyte associations during all four seasons and when averaged across seasons (Table 4). Stocking rate adjusted to the total time available within a season was also greater in pastures with wild than with other endophyte associations throughout the year. Higher stocking rate and subsequent stocking weight on wild endophyte association was likely due to lower forage consumption per head (Schmidt and Osborn, 1993), which resulted in a need to stock pastures with more cattle. At times when stocking rate was not high enough, forage mass in pastures with wild endophyte association became greater than with other endophyte associations (Fig. 1).

Cattle performance with tall fescue–endophyte associations interacted significantly with season (Table 4). Average daily gain was greater under endophyte-free and novel endophyte than under wild endophyte association during winter, spring, and autumn, but not different in summer. Lower cattle performance under wild endophyte than endophyte-free association has been reported at many locations (Stuedemann and Hoveland, 1988; Schmidt and Osborn, 1993; Gunter and Beck, 2004). Average daily gain of steers consuming low endophyte-infected forage was 0.72 ± 0.11 kg head^{-1} d^{-1} and consuming high endophyte-

Table 4
Cattle performance and productivity averaged across fertilization regimes as affected by season and tall fescue–endophyte association (free is no endophyte, novel is selected strain with low ergot alkaloid production, and wild is natural strain with high ergot alkaloid production)

Tall fescue–endophyte association	Season				Yearly
	Winter	Spring	Summer	Autumn	
Total stocking weight (Mg ha^{-1})					
Free	0.72	1.05	1.06	0.70	0.92
Novel	0.68	1.07	1.04	0.68	0.92
Wild	0.83	1.28	1.28	0.80	1.10
L.S.D. ($p = 0.1$)	0.13*	0.19*	0.14*	0.08*	0.12*
Stocking rate (head ha^{-1})[a]					
Free	0.8	3.3	2.0	2.5	2.2
Novel	0.8	3.4	2.0	2.5	2.2
Wild	1.0	4.3	2.8	2.9	2.8
L.S.D. ($p = 0.1$)	0.2*	0.7*	0.4*	0.2*	0.3*
Live-weight gain (kg ha^{-1})					
Free	61	298	118	126	603
Novel	69	306	116	131	622
Wild	63	244	147	97	552
L.S.D. ($p = 0.1$)	12	50*	4*	37	86
Average daily gain (kg head^{-1} d^{-1})					
Free	0.77	0.97	0.66	0.57	0.76
Novel	0.93	0.98	0.66	0.64	0.80
Wild	0.67	0.64	0.59	0.42	0.57
L.S.D. ($p = 0.1$)	0.13*	0.04*	0.08	0.09*	0.05*

[a] Adjusted to total time available, not just the time on paddocks.
* Following L.S.D. value indicates significance among means.

infected forage was 0.44 ± 0.11 kg head^{-1} d^{-1} among studies in 10 states of the southeastern USA (Schmidt and Osborn, 1993). During 3 years of spring and autumn grazing by yearling calves at two locations in Georgia, average daily gain was 0.85 ± 0.11 kg head^{-1} d^{-1} with endophyte-free, 0.79 ± 0.04 kg head^{-1} d^{-1} with novel endophyte association, and 0.44 ± 0.11 kg head^{-1} d^{-1} with wild endophyte association (Parish et al., 2003). With 3 years of grazing of 'Georgia 5' tall fescue pastures in northern Georgia by Angus cow-calf pairs from March to September, average daily gain of calves was 1.09 kg head^{-1} d^{-1} with novel endophyte association and 0.93 kg head^{-1} d^{-1} with wild endophyte association (Watson et al., 2004). Average daily gain of cows was also affected (0.29 kg head^{-1} d^{-1} versus 0.12 kg head^{-1} d^{-1} with novel and wild endophyte association, respectively).

Average daily gain was lowest in our study during summer and autumn, but was not different among tall fescue–endophyte associations in summer, which contradicts a perception that cattle performance would be reduced the most by wild endophyte association in the heat of the summer. We found greatest depression in performance of cattle grazing wild endophyte in spring and autumn. Average daily gain was relatively high in all endophyte associations in winter, but because of the near continuous grazing throughout the year whenever forage mass was sufficient, relatively low forage mass was available during winter months that limited the number of grazing days during this period of apparent high forage quality. In Missouri, stockpiled tall fescue with wild endophyte association was shown to decline in quality during the course of winter, but also declined in ergot alkaloid concentration (Kallenbach et al., 2003). Ergot alkaloid production in tall fescue appears to be affected by a number of factors, but is often greatest in spring and autumn (Belesky et al., 1987, 1988), coinciding with the time of greatest tall fescue forage growth and largest depression in cattle performance (Table 4).

Comparisons of cattle grazing novel endophyte versus endophyte-free tall fescue have indicated no difference in cattle performance (Parish et al., 2003; Gunter and Beck, 2004). When averaged across seasons and years, cattle performance in our study was statistically similar, but with a trend towards higher performance with novel than endophyte-free association. In winter, the novel endophyte association actually enhanced cattle performance. Although tall fescue composition was slightly lower and annual grass was higher under endophyte-free than novel endophyte association in 2004, the difference was not expected to lead to major cattle performance differences at this early stage of pasture development.

Cattle live-weight gain was affected by tall fescue–endophyte association differently throughout the year (Table 4). In winter, weight gain averaged only 64 kg ha^{-1} and was not affected by tall fescue–endophyte association. Weight gain was low, mainly due to limited growth of forage during this cold period and no stockpile of forage from autumn. In spring, weight gain was highest of all seasons (mean of 283 kg ha^{-1}) and significantly higher in pastures with endophyte-free and novel endophyte than with wild endophyte association. In summer, weight gain was moderate (mean of 127 kg ha^{-1}), but significantly higher in pastures with wild than with other endophyte associations. Weight gain in summer was moderate due to high temperature and evapotranspiration that limited the ability of tall fescue to utilize precipitation. This was despite the fact that summer received the highest precipitation of any season (Table 2). In autumn, weight gain remained moderate (mean of 118 kg ha^{-1}) as in summer and was not different among endophyte associations.

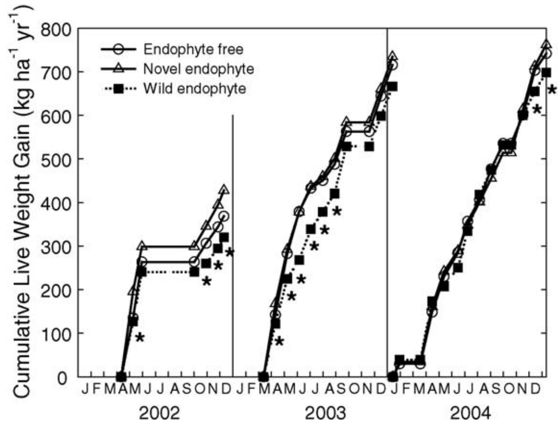

Fig. 2. Cumulative cattle weight gain as affected by tall fescue–endophyte association during the calendar years of 2002 to 2004. Asterisk below group of symbols indicates significance between at least two means at $p < 0.1$.

Averaged across seasons and years, total cattle live-weight gain was not significantly different among endophyte associations (Table 4). Cumulative weight gain during each of the three calendar years had different patterns (Fig. 2), partly due to quantity and distribution of forage within a year (Fig. 1; Table 5). During 2002, stocking of pastures occurred only in spring and autumn (total of 121 d), due to newly established pastures that were still sensitive to trampling and that received relatively low precipitation during summer. Cumulative weight gain

Table 5
Hay yield (Mg ha^{-1}) from inorganically fertilized tall fescue with novel endophyte

Harvest period	Year of harvest		
	2002	2003	2004
Spring	2.85 ± 0.33	1.00 ± 0.02	1.31 ± 0.13
Summer	–	3.96 ± 0.23	1.94 ± 0.44
Autumn	–	–	1.22 ± 0.05
Yearly total	2.85 ± 0.33	4.95 ± 0.22	4.47 ± 0.27

Harvests were on 31 May 2002, 17 April 2003, 5 September 2003, 28 April 2004, 10 July 2004, and 19 October 2004.

during 2002 was greater ($p = 0.05$) under novel than under wild endophyte by the end of the year. During 2003, pastures were stocked for 240 d. Beginning in spring and continuing into summer, cumulative weight gain was greater under endophyte-free and novel endophyte than under wild endophyte association. However by the end of summer and continuing to the end of 2003, cumulative weight gain was not different among tall fescue–endophyte associations. During 2004, pastures were stocked for 299 d, with breaks only in late winter and early autumn. Cumulative weight gain was not different among tall fescue–endophyte associations until the very end of autumn and beginning of winter, when cumulative gain became greater ($p = 0.07 \pm 0.04$) under endophyte-free and novel endophyte than under wild endophyte association. During the more complete grazing years of 2003 and 2004, cumulative cattle weight gain was 739 ± 19 kg ha^{-1} under endophyte-free and novel endophyte associations and 682 ± 23 kg ha^{-1} under wild endophyte association.

Our results of statistically similar cattle weight gain under endophyte-free and wild endophyte association are in contrast to several previous reports of major difference in animal weight gain between these endophyte associations. Crossbred steers grazing 'Kentucky 31' tall fescue during 4 years (186 ± 11 d year^{-1}) in central Alabama gained 478 ± 62 kg ha^{-1} under endophyte-free association and 363 ± 139 kg ha^{-1} under wild endophyte association (Hoveland et al., 1983). Cattle gain was different in 3 of 4 years and when averaged across years. Crossbred steers grazing 'Kenhy' tall fescue during 3 years (82 ± 17 d year^{-1}) in northcentral Texas gained 378 ± 74 kg ha^{-1} under endophyte-free association and 257 ± 81 kg ha^{-1} under wild endophyte association (Read and Camp, 1986). Cattle gain was different in two of four seasons and when averaged across years. Gunter and Beck (2004) summarized four studies conducted in Alabama (224 d, Jesup), Georgia (154 d, Jesup), Louisiana (112 d, Georgia 5), and Tennessee (206 d, Kentucky 31) and reported mean cattle gain of 430 and 464 kg ha^{-1} under novel and endophyte-free associations, respectively, and 333 kg ha^{-1} under wild endophyte association. In our study, grazing was more continuous throughout the year and this may have mitigated cattle response to endophyte association by allowing animals to become adjusted to ingestion of ergot alkaloids.

3.3. *Effect of grazing versus haying*

Percentage of ground cover as tall fescue increased with pasture age more when grazed than when hayed (Table 3). The lower ground cover of tall fescue under hayed than grazed management in 2004 may have been a result of hay cutting immediately prior to botanical assessment, since bare ground also became a significantly larger component under hayed management. Annual grasses were initially a larger component of grazed than hayed management, but this effect was reversed in the 2004 evaluation, suggesting that haying may have stimulated crabgrass development following hay cutting.

Quantity of hay produced was related to the amount and distribution of precipitation among years (Table 5). With high precipitation in summer of 2003, hay yield was highest in 2003. High rainfall in September 2004 caused by passing hurricane storms resulted in a third harvest of hay in 2004 that boosted annual hay yield. Potential cattle gain assuming hay were fed to animals similar in condition to those grazing pastures (i.e., 340 kg head^{-1}, mean intake of 8.4 kg head^{-1} d^{-1}) would have been 287 kg ha^{-1} in 2002, 499 kg ha^{-1} in 2003, and 451 kg ha^{-1} in 2004 [calculation based on National Research Council (1996) equations assuming 10.2 kJ g^{-1} forage]. Therefore, grazing of inorganically fertilized tall fescue with novel endophyte association resulted in greater cattle gain (664 ± 204 kg ha^{-1}) than would have occurred with haying (412 ± 111 kg ha^{-1}).

4. Conclusions

Fertilization source did not interact significantly with tall fescue–endophyte association for any of the response variables measured in this study, suggesting that a greater supply of nutrients other than *N* with broiler litter did not alter pasture and cattle responses to tall fescue–endophyte association. However, seasonal differences in cattle production and performance in response to fertilization source suggested that altering nutrient availability could be partly used to overcome poor animal performance. Weight gain per land area was negatively affected by wild endophyte association only in spring and autumn, but was positively affected in summer due to higher stocking rate. Novel endophyte association maintained persistence during the first 3 years of pasture grazing and led to high performance and production of yearling heifers with grazing throughout the year. Significant opportunities to manage wild endophyte association of tall fescue are possible (e.g., manipulating fertilizer quantity and timing and season of grazing), so that negative effects of ergot alkaloids might be avoided without producers having to endure the cost of reseeding old stands of wild endophyte-infected tall fescue.

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