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Intake and Digestion of 'Jesup' Tall Fescue Hays with a Novel Fungal Endophyte, without an Endophyte, or with a Wild-Type Endophyte

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ABSTRACT

Tall fescue (*Festuca arundinacea* Schreb.) is an important forage resource for beef (*Bos taurus* L.) production in the North–South transition zone. Recently, the cultivar 'Jesup' was released to provide improved stand survival when infected with a novel (nontoxic) endophyte marketed as MaxQ (Pennington Seed, Madison, GA), and warrants evaluation as a source of winter hay for beef cattle. Intake and digestion experiments were conducted to evaluate Jesup tall fescue containing the MaxQ endophyte (presumably without ergot alkaloids), Jesup with no endophyte, and Jesup with a wild-type endophyte capable of producing ergot alkaloids. Initial growth of the three endophyte treatments was harvested in April and a regrowth harvested in June. These six hays were fed to goats (*Capra hircus* L.) and sheep (*Ovis aries* L.). The hays harvested in June were also fed to cattle. The digestibility of the endophyte treatments was similar but goats had greater daily dry matter intake when fed MaxQ compared with wild-type hay (2.63 vs. 2.43 kg 100^{-1} kg body weight; $P = 0.07$) while intake was similar to the endophyte-free hay. Sheep consumed hays similarly, regardless of harvest date, as did steers fed the June harvest. Daily intake of hays harvested in April and June were similar for goats, whereas sheep consumed more of the April hays (2.89 vs. 2.57 kg 100^{-1} kg body weight; $P < 0.01$) and both digested the April hays to a greater extent. Endophyte status of the hays had little influence on their quality.

TALL FESCUE is an important forage resource for beef cattle enterprises across the North–South transition zone (Burns and Chamblee, 1979; Stuedemann and Hoveland, 1988). In the upper South, tall fescue provides forage for pasture in late winter through spring and in the fall. Tall fescue is also an important source of hay, with harvest commonly taken from understocked or unused pasture land in late April through June. Further, late summer growth can be stockpiled into the fall for grazing during the late autumn and winter periods.

The persistence and long-term survival of tall fescue in the transition zone has been associated with the presence of the endophyte *Neotyphodium coenophialum* (Morgan-Jones & Gams.) Glenn, Bacon & Hanlin comb. nov. (Bacon et al., 1986; Bouton et al., 1993, 2002; Bacon, 1995; Porter, 1995). The same endophyte, however, has been associated with tall fescue toxicosis (Hill et al., 1994) expressed, in part, as reductions in animal weight gains (Stuedemann and Hoveland, 1988; Fribourg et al., 1991; Schmidt and Osborn, 1993). Reduced gains have been largely attributed to ingestion of ergot alkaloids produced by the endophyte (Aldrich et al., 1993a, 1993b; Rice et al., 1997; Burke et al., 2001a, 2001b). Reduced animal performance is accompanied by either reduced daily dry matter intake (Emile et al., 2000) or dry matter digestion (Hannah et al., 1990; Fiorito et al., 1991) or both (Aldrich et al., 1993a; Strickland et al., 1993).

This lack of consistency is likely associated with the degree of stress on the animal and related to ambient temperature, concentration and type of ergot alkaloids present in the plant, the quantity of alkaloids in the animal's diet, and the physiology of the individual animal. Clinical signs of fescue toxicosis are often more severe when animals are consuming *N. coenophialum*-infected tall fescue while ambient temperatures approach or exceed 31°C (Bacon et al., 1986). Under such conditions, a 10% unit increase in endophyte level has been associated with a 0.45 kg reduction in daily performance (Stuedemann and Hoveland, 1988; Fribourg et al., 1991).

Recently, 'Jesup' tall fescue was developed in Georgia as an endophyte-free cultivar and released based on improved stand persistence for the Southern Coastal Plain (Bouton et al., 1997), and high animal performance in the Southern Piedmont (Hoveland et al., 1997). Further, a novel (nontoxic) endophyte of *N. coenophialum* was incorporated into Jesup providing enhanced summer survival without reducing animal performance (Bouton et al., 2002). Jesup tall fescue is presently being marketed under the trademark of MaxQ tall fescue (Pennington Seed, Madison, GA; Bouton et al., 2002) and may offer improved persistence and animal performance in grazing systems across the Mid-Atlantic Region.

In the Southern Piedmont, hay is typically managed in concert with utilization by grazing. The hay harvests typically occur from late spring into early summer. Hay is generally fed on an as-needed basis during late fall and winter. Consequently, stand longevity and desirable hay quality are essential characteristics for an improved cultivar. Although the novel endophyte was introduced into Jesup (MaxQ) tall fescue to aid stand persistence, it is unclear how it may affect dry matter intake and digestion by animals when it is fed as hay. The objective of this study was to determine the dry matter intake and digestion of Jesup hay when containing the MaxQ endophyte compared with Jesup that is endophyte free and with Jesup containing a wild-type endophyte utilizing separate experiments with goats, sheep, and cattle. The

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; IVTDMD, in vitro true dry matter disappearance; MSD, minimum significant difference; NDF, neutral detergent fiber.

digestible intake of dry matter, crude protein, and fiber fractions was also tested for variation within each of the three-animal species experiments.

MATERIALS AND METHODS

Experimental Hays

The experimental hays were harvested from three separate well-established stands of Jesup tall fescue grown on a Cecil clay loam (fine, kaolinitic, thermic Typic Kandiudults) at the Reedy Creek Road Field Laboratory, Raleigh, NC. One stand consisted of Jesup free of endophyte, the second of Jesup with the MaxQ endophyte presumably without ergot-like alkaloid production, and the third stand was Jesup with a wild-type endophyte presumably capable of producing ergot-like alkaloids. All three stands representing endophyte status were cut for evaluation at each harvest date.

All stands of tall fescue were flail chopped to an 8-cm stubble in late February to remove winter growth. The areas were initially treated with lime at 1680 kg ha^{-1}, and then P and K were applied according to soil test. Ammonium nitrate was top-dressed in early March and again after the removal of the initial growth at 78 kg N ha^{-1}. Initial growth was cut in the late vegetative to flag-leaf stage on 20 April, and the vegetative regrowth was cut 29 June 2001 when canopy height reached approximately 30 cm. Maturity stage was similar among endophyte status within each harvest.

All forage was cut with a mower conditioner set at a 10-cm height. After cutting, and again each day, the forage was redistributed with a tedder to aid drying. The forage was then baled with a conventional square baler and stored on wooden pallets in a metal building until fed. Just before feeding, the hays were passed through a hydraulic bale processor (Van Dale 5600, J. Starr Industries, Fort Atkinson, WI) with stationary knives spaced 10 cm apart. This procedure cut the hay into length of 7 to 13 cm to aid utilization by the animals while avoiding leaf loss.

Experimental Animals

Six Boer goats and Katahdin sheep were selected for uniformity from the University herds. The six Boer goats used in Exp. 1 had initial weights ranging from 27 to 31 kg, and the six Katahdin sheep used in Exp. 2 had initial weights ranging from 32 to 37 kg. Both goats and sheep were held in digestion crates in an enclosed, but well-ventilated metabolism unit with moderate temperature control (ambient air maintained >13°C and <24°C) with free access to trace mineralized salt and water. When animals were placed in crates, they were fitted with a collection harness for future fecal collections. After initial conditioning to the crates and harness and following standardization, each animal was randomly assigned to one of the six hay treatments. At initiation of the digestion phase, canvas bags with plastic inserts were positioned on the collection harness for total fecal collection. The bags were emptied and feces processed daily.

Fifteen Angus steers weighing from 228 to 322 kg were used in Exp. 3. The steers were confined to a covered, outdoor, raised platform equipped with electronic gates (American Calan Inc., Northwood, NH) as previously described (Burns et al., 1994) during the intake phase of the study. Each steer was keyed electronically to allow access to only one feeder, but animals could lounge together and had free access to mineralized salt and water. After conditioning to the gates, and following standardization, animals were blocked by weight and each animal randomly assigned to one of the three forage treatments within each block. For the digestion phase (immediately following each period of the intake phase), the steers were moved from the intake area into the adjacent metabolism section with moderate temperature control (>13°C and <29°C) and into digestion crates with free access to mineralized salt and water. Feces were collected on plastic sheets placed on the floor immediately in back of the crates and processed daily.

Intake and Digestion Trials

The three experimental forages harvested as initial growth and again as regrowth (six hays) were evaluated together in experiments using wether goats (Exp. 1) and sheep (Exp. 2). The goats and sheep made up separate experiments conducted in six by six Latin square designs (three experimental forages and two harvest dates). The three hays from the 29 June regrowth harvest were also evaluated by steers (Exp. 3) using a randomized complete block design (blocked by animal weight) with five steers per treatment.

Animals in each experiment were standardized for 14 d on a bulk source of endophyte-free Jesup hay. Each experimental period for goats (Exp. 1) and sheep (Exp. 2) consisted of 21 d, with the first 5 d allowed for adjustment and with total fecal collection the last 5 d. In the case of steers, the experimental period consisted of a 21-d intake phase followed by a 12-d digestion phase (7-d adjustment and 5-d collections).

In both the intake and digestion phases, the forage treatments were fed twice daily allowing a 15% excess. Adjustments were based on the intake of the previous day. Calculation of ad libitum dry matter intake was based on the last 16 d for goats and sheep and the last 14 d for steers. A daily sample of the offered forage was obtained for each animal and contributed to a composite sample on a weekly basis in the intake phase and for the 5-d collection period in the digestion phase. Orts were also taken twice daily and saved for each animal and a composite sample saved for each week in the intake phase and for the 5-d collection period in the digestion phase. The weekly composite samples of the offered forage and orts were further composited for the intake period. All samples were thoroughly mixed, subsampled, oven dried (55°C) to a constant weight (generally 48 h), and used for dry matter determination and stored for grinding. During the digestion phase, feces were collected and weighed for each of five consecutive 24-h periods. Feces were thoroughly mixed daily and a proportion (5% of total) of the fresh weight was placed in a freezer (−14°C). Following the 5-d collection, the composite frozen samples were oven dried (55°C) to constant weight (generally 48 h) for dry matter determination, and stored for grinding.

Laboratory Analyses

All feed, ort, and fecal samples from the intake and digestion phases of each experiment were ground in a Wiley mill to pass a 1-mm screen, scanned in a near-infrared reflectance spectrophotometer (NIRS), and the *H* statistic (0.6) used to identify select samples by spectra for laboratory analyses to develop NIRS prediction equations for all samples.

In vitro true dry matter disappearance (IVTDMD) was determined by 48 h fermentation in a batch fermentation vessel (Ankom Technology Corp., Fairport, NY) with artificial saliva and rumen inoculum according to Burns and Cope (1974). Ruminal inoculum was obtained from a mature Hereford steer fed a mixed alfalfa (*Medicago sativa* L.) and orchardgrass (*Dactylis glomerata* L.) hay. Total N was determined by autoanalyzer (Association of Official Analytical Chemists, 1990), and crude protein (CP) was estimated as 6.25 times total N.

Table 1. The observed range of each forage constituent predicted by near infrared reflectance spectrophotometer, its standard error of calibration (SEC), and standard error of crossvalidation (SEV).

Variable†	N	Range	SEC	SEV	Mean
		g kg^{-1}			
IVTDMD	115	619–833	10.9	12.9	745
CP	114	105–193	2.1	2.7	148
NDF	112	564–706	7.3	8.5	627
ADF	115	273–405	4.6	5.9	310
CELL	115	232–349	3.5	4.4	271
Lignin	111	21.1–54.8	1.9	2.1	32.2

† IVTDMD = in vitro true dry matter disappearance; CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; CELL = cellulose.

Fiber fractions consisting of neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose, and sulfuric acid lignin were estimated in a batch processor (Ankom Technology Corp., Fairport, NY) using reagents according to Van Soest and Robertson (1980). Hemicellulose was determined by difference (NDF − ADF). Laboratory values were used to develop NIRS calibration equations from feed and ort samples and separately from fecal samples to predict each sample from the reflectance spectrum (Table 1).

Endophyte infection was verified by randomly cutting basal tillers from fescue in each hay field (150 tillers), placing them in plastic bags (Randell-Schadel, 1995) on ice and immediately delivering them to the Tall Fescue Endophyte Testing Laboratory, N.C. Dep. of Agric., Raleigh, N.C. Endophyte infestation averaged 94.0, 95.3, and 5.3% for the wild-type, MaxQ, and the endophyte-free fields, respectively. Differences in total ergot alkaloid concentrations of the fed hays were verified using the ELISA test (N.S. Hill, University of Georgia, Athens, GA) according to Adcock et al. (1997). The wild-type, MaxQ, and the endophyte-free hays averaged 221, 103, and 110 μg kg^{-1}, respectively (minimum significant difference = 33 μg kg^{-1}; CV = 9.8%).

Statistical Analyses

Data from the intake and digestion phases for Exp. 1 and 2 were analyzed as six by six Latin squares using a mixed model. The model included terms for animal, period, endophyte status, and harvest (Steel and Torrie, 1980). Animal and period were random effects and endophyte status and harvest were fixed effects. Data from the intake and digestion phases for Exp. 3 were analyzed as a randomized complete block. The mixed model included a random term for blocks and a fixed term for endophyte status. Means for all variables found significant were separated using the minimum significant difference (MSD) based on the Waller–Duncan k ratio t test. Because of the expected variation in estimates of animal intake and digestion, an a priori decision was made to test these variables with the k ratio set at 50 and to reject the null hypothesis with $P \leq 0.10$. All forage and fecal composition data were tested with the k ratio set at 100 and the null hypothesis was rejected for $P \leq 0.05$.

RESULTS

The hays harvested on 20 April were grown under mild conditions with rainfall above average in March and slightly below average in April (Table 2). The regrowth forage harvested 29 June grew under warmer temperatures with a mean of 23.7°C in June. Severe moisture stress did not occur during either growth period. All hays were field cured during 3 d without exposure to rain, were preserved without heat damage, and were stored out of direct sunlight.

Table 2. Thirty-year mean and departures from the mean for climatological data recorded ≈5 km from the experimental site for the growing period preceding the 20 April and 29 June harvests.†

	30-yr mean		Departure for growth period	
Item	Rainfall	Temp.	Rainfall	Temp.
	mm	°C	mm	°C
April harvest				
February	88.1	6.1	−28.7	2.3
March	102.4	10.4	78.2	−0.9
April	71.1	15.1	−27.4	0.9
June harvest				
May	96.3	19.4	−6.6	0.6
June	86.9	23.7	28.5	1.2

† Data recorded at the Raleigh–Durham Int. Airport and reported by the National Oceanic and Atmospheric Administration.

Goat Responses

Neither the goat responses measured nor the composition of the hays showed an endophyte status by harvest date interaction. Consequently, only the main effects are reported.

The daily intake of goats fed the MaxQ hay was greater compared with the wild-type hay (2.63 vs. 2.43 kg 100^{-1} kg BW; $P < 0.10$), but similar to the endophyte-free hay (Table 3). The daily intakes of the endophyte-free and wild-type hays were similar. Also, dry matter intake was similar for the two harvest dates.

Apparent digestion for dry matter, CP, and fiber fractions were similar for all three hays (Table 3). The hays harvested in April had greater digestibility for dry matter, CP, and fiber fractions compared with the June-harvested hays.

The daily digestible intake of CP was greater with the MaxQ endophyte than the wild type (Table 4; $P < 0.01$). Even though the digestible dry matter intake did not have a significant F test ($P = 0.12$), the MSD (k ratio = 50) is still a valid test and indicated that the MaxQ hay and wild-type hays differed. The daily digestible intake of dry matter, CP, and the fiber fractions was greater for the hays harvested in April than the hays harvested in June.

The composition of the hays differed ($P \leq 0.05$) among endophyte status for IVTDMD, CP, NDF, hemicellulose, and cellulose, but not for ADF or lignin (Table 5). MaxQ and endophyte-free hays were similar according to the calculated MSD values, but the MaxQ and endophyte-free hays differed from the wild type in IVTDMD and CP concentrations. The wild type had greater concentrations of NDF and hemicellulose than the endophyte-free hay, but the wild type was similar to MaxQ. The cellulose concentration of the wild type was greater than the MaxQ, but the difference was only equal to the MSD, and the endophyte-free line was intermediate.

The hays harvested in April had greater concentrations of IVTDMD and CP and lower fiber fractions than hays harvested in June (Table 5). It should be noted that

Table 3. Dry matter intake and digestion of dry matter, crude protein (CP), and fiber fractions of tall fescue hays harvested in April and June with a wild type, MaxQ, or no endophyte and fed to goats.

Item	Daily DM intake	Apparent Digestion†					
		DM	CP	NDF	ADF	HEMI	CELL
	kg 100 kg^{-1} BW‡	g kg^{-1}					
Endophyte							
Wild type	2.43§	636	631	660	639	792	701
MaxQ	2.63	635	654	650	624	771	687
Free	2.55	627	638	645	618	787	686
MSD¶	0.16	24	23	26	30	41	26
Harvest							
April	2.58#	679	676	701	672	880	735
June	2.50	587	606	603	583	688	648
Significance (*P*)							
Endophyte (E)	0.07	0.70	0.15	0.51	0.37	0.53	0.41
Harvest (H)	0.27	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
E × H	0.91	0.82	0.65	0.67	0.69	0.41	0.57

† DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.
‡ Body weight basis.
§ Each value is the mean of six animals (n = 6).
¶ MSD = minimum significant difference based on the Waller–Duncan k ratio (k = 50) t test.
# Each value is the mean of six animals and three hay treatments (n = 18).

Table 4. Daily digestible intakes of dry matter, crude protein (CP), and fiber fractions of tall fescue hays harvested in April and June with a wild type, MaxQ, or no endophyte and fed to goats.

Item	DM†	CP	NDF	ADF	HEMI	CELL
	kg 100 kg^{-1} BW‡					
Endophyte						
Wild type	1.54§	0.22	1.01	0.48	0.61	0.47
MaxQ	1.67	0.27	1.06	0.49	0.64	0.48
Free	1.60	0.25	1.00	0.48	0.61	0.47
MSD¶	0.12	0.02	0.08	0.05	0.05	0.04
Harvest						
April	1.75#	0.29	1.07	0.50	0.69	0.49
June	1.46	0.21	0.97	0.47	0.55	0.46
Significance (*P*)						
Endophyte (E)	0.12	<0.01	0.39	0.80	0.37	0.69
Harvest (H)	<0.01	<0.01	<0.01	0.07	<0.01	0.10
E × H	0.75	0.33	0.91	0.95	0.83	0.83

† DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.
‡ Body weight basis.
§ Each value is the mean of six animals (n = 6).
¶ MSD = minimum significant difference based on the Waller–Duncan k ratio (k = 50) t test.
# Each value is the mean of six animals and three endophyte treatments (n = 18).

and endophyte-free hays harvested in June compared with April (32 vs. 26 g kg^{-1}), while concentrations in the wild-type hay were similar (30 g kg^{-1}).

Sheep Response

As noted with goats, none of the sheep responses measured or the composition of the hays showed a significant endophyte by harvest date interaction. Consequently, only the data for the main effects are reported (Table 6). The daily dry matter intake by sheep was not altered by endophyte status. The hays harvested in April, however, were consumed in greater amounts compared with hays harvested in June.

The apparent digestion of dry matter, CP, and fiber fractions of the hays were similar among the endophyte treatments (Table 6). The digestibility of the dry matter and fiber fractions of the hays harvested in April were greater than the hays harvested in June. The digestibility of CP, however, was similar between harvest dates.

Within the ANOVA, the digestible daily intakes of dry matter, CP, and fiber fractions were not altered by endophyte status (Table 7). However, the MSD (k ratio = 50) indicated small differences between the daily diges-

Table 5. In vitro true dry matter disappearance, crude protein (CP), and fiber fractions of tall fescue hays with wild type, MaxQ, or no endophyte fed to goats in intake and digestion trials.

Item	IVTDMD†	CP	NDF	ADF	HEMI	CELL	Lignin
	g kg^{-1}						
April harvest							
Wild type	741‡	144	631	312	319	275	29
MaxQ	771	153	620	303	318	268	28
Free	769	154	615	307	308	270	30
MSD§	28	9	13	10	4	7	3
Harvest							
April	803¶	166	595	290	305	255	27
June	718	135	649	324	325	286	31
Significance (*P*)							
Endophyte (E)	0.05	0.03	0.03	0.09	<0.01	0.05	0.34
Harvest (H)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
E × H	0.61	0.55	0.64	0.39	0.31	0.31	0.02

† IVTDMD = in vitro true dry matter disappearance; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.
‡ Each value is the mean of samples from six animals (n = 6).
§ MSD = minimum significant difference based on the Waller–Duncan k ratio (k = 100) t test.
¶ Each value is the mean of samples from six animals and three hay treatments (n = 18).

lignin concentrations gave an endophyte status by harvest date interaction (P = 0.02; data not shown). This was the result of greater lignin concentrations for MaxQ

Table 6. Daily intake of dry matter and digestion of dry matter, CP, and fiber fractions of tall fescue hays harvested in April and June with a wild type, MaxQ, or no endophyte and fed to sheep or cattle.

Item	Daily DM intake	Apparent digestion†					
		DM	CP	NDF	ADF	HEMI	CELL
	kg 100 kg^{-1} BW‡	g kg^{-1}					
Sheep Trial							
Endophyte							
Wild type	2.71§	630	645	642	622	733	682
MaxQ	2.78	645	652	661	637	779	696
Free	2.72	646	669	656	634	763	693
MSD¶	0.08	19	42	30	35	57	35
Harvest							
April	2.89#	672	666	691	668	833	727
June	2.57	609	645	614	594	684	655
Significance (*P*)							
Endophyte (E)	0.21	0.21	0.48	0.41	0.63	0.23	0.66
Harvest (H)	<0.01	<0.01	0.20	<0.01	<0.01	<0.01	<0.01
E × H	0.18	0.88	0.50	0.82	0.74	0.72	0.76
Cattle trial (June harvest)							
Endophyte							
Wild type	2.31††	618	595	666	641	677	724
MaxQ	2.40	623	599	657	644	670	717
Free	2.44	634	628	672	646	695	722
Significance (*P*)							
Endophyte	0.83	0.77	0.24	0.98	0.57	0.43	0.93
MSD	0.49	42	41	45	51	41	44

† DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.
‡ Body weight basis.
§ Each value is the mean of six animals (n = 6).
¶ MSD = minimum significant difference based on the Waller–Duncan k ratio (k = 50) t test.
# Each value is the mean of six animals and three hay treatments (n = 18).
†† Each value is the mean of five animals (n = 5).

Table 7. Daily digestible intakes of dry matter, crude protein (CP), and fiber fractions of tall fescue hays harvested in April and June with a wild type, MaxQ, or no endophyte and fed to sheep or cattle.

Item	DM†	CP	NDF	ADF	HEMI	CELL
	kg 100 kg^{-1} BW‡					
Sheep Trial						
Endophyte						
Wild type	1.71§	0.26	1.10	0.51	0.63	0.50
MaxQ	1.80	0.27	1.15	0.54	0.70	0.52
Free	1.76	0.29	1.08	0.53	0.65	0.50
MSD¶	0.08	0.04	0.09	0.06	0.07	0.06
Harvest						
April	1.94#	0.31	1.20	0.57	0.75	0.54
June	1.57	0.24	1.02	0.48	0.58	0.47
Significance (*P*)						
Endophyte (E)	0.11	0.52	0.29	0.60	0.12	0.59
Harvest (H)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
E × H	0.38	0.56	0.35	0.45	0.31	0.41
Cattle trial (June harvest)						
Endophyte						
Wild type	1.43††	0.18	1.00	0.47	0.52	0.48
MaxQ	1.49	0.20	1.01	0.48	0.54	0.48
Free	1.55	0.22	1.05	0.49	0.56	0.49
Significance (*P*)						
Endophyte	0.75	0.16	0.87	0.94	0.81	0.97
MSD	0.33	0.04	0.24	0.11	0.13	0.11

† DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.
‡ Body weight basis.
§ Each value is the mean of six animals (n = 6).
¶ MSD = minimum significant difference based on the Waller–Duncan k ratio (k = 50) t test.
# Each value is the mean of six animals and three endophyte treatments (n = 18).
†† Each value is the mean of five animals (n = 5).

tible dry matter and hemicellulose intakes of MaxQ and the wild type. Hays harvested in April had greater daily digestible intakes of dry matter, CP, and fiber fractions compared with hays harvested in June.

The IVTDMD, CP, and fiber fractions were generally similar regardless of endophyte status (Table 8). An exception was that hemicellulose in MaxQ hay was greater than in endophyte-free hay with the wild-type intermediate. In addition, the MSD (k ratio = 100; F test P = 0.07) indicated that the concentration of lignin in the endophyte-free hay was greater than in the wild type or MaxQ. Concentration of IVTDMD and CP were greater in the April-harvested forage; whereas NDF and its fiber constituents were consistently lower.

Steer Responses

Only hays from the June harvest were selected for evaluation by cattle. Daily dry matter intake of steers was not altered by endophyte status (Table 6). Furthermore, forages were of similar digestibilities (Table 7) and daily digestible intakes of dry matter, CP, NDF, and constituent fiber fractions.

The composition of the hays differed among endophyte status for IVTDMD ($P < 0.01$) and CP ($P < 0.01$) (Table 8). The IVTDMD of the fescue containing the wild-type endophyte was less than the IVTDMD of the MaxQ and endophyte-free hays. The CP concentration of the endophyte-free hay was greater than for wild-type hay but similar to MaxQ. Concentrations of NDF, ADF, hemicellulose, cellulose, and lignin were all similar (P ranged from 0.07 to 0.46).

DISCUSSION

Testing of the infection levels of the tall fescue stands used for hay production showed the wild type was 94.0% infected, MaxQ was 95.3% infected, and the endophyte-free stand was 5.3% infected. Total ergot alkaloid concentrations of the fed hays averaged 221, 103, and 110 μg

Table 8. In vitro true dry matter disappearance, crude protein (CP), and fiber fractions of tall fescue hays harvested in April and June with a wild type, MaxQ, or no endophyte fed to sheep or cattle in intake and digestion trials.

Item	IVTDMD†	CP	NDF	ADF	HEMI	CELL	Lignin
	g kg^{-1}						
Sheep Trial							
Endophyte							
Wild type	765‡	150	619	303	317	268	28
MaxQ	765	149	626	304	323	269	28
Free	769	157	616	305	311	267	31
MSD§	47	17	28	21	8	19	3
Harvest							
April	803¶	163	601	292	309	257	27
June	730	141	641	316	325	279	31
Significance (*P*)							
Endophyte (E)	0.96	0.44	0.57	0.95	0.02	0.94	0.07
Harvest (H)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
E × H	0.68	0.14	0.53	0.65	0.15	0.64	0.57
Cattle trial (June harvest)							
Endophyte							
Wild type	711#	129	652	319	333	283	29
MaxQ	738	135	644	312	331	279	28
Free	734	143	642	312	330	276	30
Significance (*P*)							
Endophyte	<0.01	0.03	0.08	0.35	0.46	0.26	0.07
MSD¶	16	10	12	13	8	10	3

† IVTDMD = in vitro true dry matter disappearance; NDF = neutral detergent fiber; ADF = acid detergent fiber; HEMI = hemicellulose; CELL = cellulose.
‡ Each value is the mean of samples from six animals (n = 6).
§ MSD = minimum significant difference based on the Waller–Duncan k ratio (k = 100) t test.
¶ Each value is the mean of samples from six animals and three hay treatments (n = 18).
# Each value is the mean of samples from five animals (n = 5).

kg^{-1}, respectively. The total ergot alkaloid concentrations in the hays of MaxQ (Jesup + AR 542 endophyte strain, Bouton et al., 2002) and Jesup essentially free of endophyte were of the same magnitude as reported in field trials by Bouton et al. (2002) and Hill et al. (2002). The total ergot alkaloid concentrations of the wild type in this study, although double the concentrations noted in MaxQ and the endophyte-free hays, were about 1/5 of the level reported by Bouton et al. (2002). This difference may, in part, be attributed to a lack of alkaloid stability associated with photolysis, oxidation, and rehydration of the plant tissue (Garner et al., 1993; Porter, 1995). Sun curing of forages, as done in this study, would involve several cycles of drying and rehydration. Recently, Fletcher (2005) reported that ergovaline concentrations in ryegrass (*Lolium perenne* L.) at harvest did not decline when ensiled, but when stored as hay, the concentration declined and was negligible by 207 d after harvest. Further, Kallenbach et al. (2003) reported a decline in ergovaline concentrations of about 85% between December and March in 'HiMag' tall fescue when managed as a stockpile. Further evaluation is needed to determine the degree to which concentrations of ergot-like alkaloids decline during hay-curing and storage at ambient temperature and humidity.

Harvest Date

The use of an April and June harvest in this study provided vastly different environments for the production of the experimental hays. Tall fescue harvested in April, although in a more advanced physiological stage compared with the June regrowth, was greater in nutritive value. This was reflected in greater dry matter intake by sheep and greater dry matter digestion and intake of digestible forage and forage fiber by both sheep and goats, and is attributed to cooler and moist environmental conditions (Table 2; Deinum et al., 1968; Allinson, 1971; Hemken et al., 1981).

Dry Matter

Differences among the endophyte treatments varied appreciably. Goats consumed more of the MaxQ hay compared with the hay containing the wild-type endophyte, whereas sheep and cattle consumed all three hays similarly. Differences among animal species are consistent with literature findings (Fiorito et al., 1991; Emile et al., 2000).

Dry matter digestion was similar among hays within each animal trial. Combining dry matter intake and dry matter digestion to give estimates of digestible dry matter intake showed goats and sheep, but not cattle, to have greater digestible dry matter intakes when fed MaxQ hay.

Crude Protein and Fiber Fractions

Digestibility of CP and the fiber fractions were generally similar for endophyte status within each animal species. However, the difference in apparent digestion of MaxQ hay and the wild-type hay was equal to the MSD contributing to differences in digestible CP intake ($P < 0.01$). In general, the digestible intakes of NDF and its fiber constituents were similar among endophyte status in all three experiments.

General

The composition data generally supported the animal responses obtained for goats and sheep. The greater dry matter intake obtained with goats fed MaxQ hay is consistent with its observed greater IVTDMD and CP and lower ADF and cellulose concentrations relative to the wild-type hay. In the case of sheep, dry matter intake was

similar among endophyte status and consistent with similar IVTDMD, CP, and fiber fraction concentrations. The composition data from the steer trial showed IVTDMD was least for the wild-type hay and the wild-type hay also had less CP than the endophyte-free hay. However, these differences were not reflected in steer dry matter intake ($P \geq 0.10$). In general, estimates of nutritive value from other tall fescue cultivars when compared with and without toxic endophyte have shown little response to the presence of the endophyte (Turner et al., 1990; Collins, 1991; Asay et al., 2002).

The detailed sampling protocol of daily collecting a sample of the feed offered each animal revealed variation in the composition of hay. For example, the differences in composition found among the hays in the goat trial were generally not noted in the sheep trial. Also, the means observed among hays fed from the June harvest to goats and sheep (data not shown) were generally similar for CP, hemicellulose and lignin, but in the steer trial, the statistical differences noted among the same hays occurred for different variables. In the steer trial, differences were found mainly in IVTDMD, CP, and NDF concentrations. These observations demonstrate the importance that should be placed on the daily sampling of feeds offered for accurate estimates of nutritive value of feeds utilized in animal trials. Without an adequate sampling protocol, it would be natural to assume that analyses of a limited number of bale cores from each bulk lot would be representative of the hays to be offered in each of the animal trials.

The results from this study showed that Jesup tall fescue with the MaxQ endophyte gave similar or greater animal responses as Jesup tall fescue when endophyte free. Short-term steer daily performance when steers consumed the June harvested hays averaged 0.98, 1.23, and 0.80 kg for the endophyte free, MaxQ, and wild-type endophyte hays, respectively (SE = $\pm$0.17 kg). Although these performance data are short term, they are consistent with observations of dry matter intake, dry matter digestion, and digestible dry matter intake. Steers consuming the MaxQ hay performed well relative to the other two hay treatments, and the presence of the novel endophyte did not negatively influence animal responses. These data indicated that Jesup tall fescue hay with the MaxQ endophyte should provide a suitable source of nutrients when fed during the winter in the mid-Atlantic region (National Research Council, 1996). On the other hand, hay containing the wild-type endophyte generally gave similar responses with sheep and cattle as did MaxQ or endophyte-free hays during these winter feeding trials. In all trials, animals gained weight with the mean weight of goats increasing 8 kg, sheep 11 kg, and steers gains averaged 1 kg d^{-1} as noted above. Because tall fescue stands are utilized both as a pasture and a hay source, the agronomic aspects of forage production warrant special consideration. Improved stand persistence occurs through the presence of endophyte (Arachevaleta et al., 1989); however, ergot-alkaloid producing endophytes can negatively influence animal performance during the grazing season. These latter considerations may be far more important in cultivar selection for use in production systems, than is the influence of the endophyte on nutritive value of harvested forage stored as hay for winter utilization. Further research is warranted to characterize the change in ergot-alkaloids during sun curing and storage under ambient conditions. Also, studies are needed to test hay quality of the novel endophytes in long-term performance trials with ruminants.

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