FORAGES AND PASTURES SYMPOSIUM: Managing the tall fescue–fungal endophyte symbiosis for optimum forage-animal production¹,²

G. E. Aiken³ and J. R. Strickland

ARS-USDA, Forage-Animal Production Research Unit, Lexington, KY 40546

ABSTRACT: Alkaloids produced by the fungal endophyte (Neotyphodium coenophialum) that infects tall fescue [Lolium arundinaceum (Schreb.) Darbysh.] are a paradox to cattle production. Although certain alkaloids impart tall fescue with tolerances to environmental stresses, such as moisture, heat, and herbivory, ergot alkaloids produced by the endophyte can induce fescue toxicosis, a malady that adversely affects animal production and physiology. Hardiness and persistence of tall fescue under limited management can be attributed to the endophyte, but the trade-off is reduced cattle production from consumption of ergot alkaloids produced by the endophyte. Improved understanding and knowledge of this endophyte-grass complex has facilitated development of technologies and management systems that can either mitigate or completely alleviate fescue toxicosis. This review discusses the research results that have led to development of 5 management approaches to either reduce the severity of fescue toxicosis or alleviate it altogether. Three approaches manipulate the endophyte-tall fescue complex to reduce or alleviate ergot alkaloids: 1) use of heavy grazing intensities, 2) replacing the toxic endophyte with nonergot alkaloid-producing endophytes, and 3) chemical suppression of seed head emergence. The remaining 2 management options do not affect ergot alkaloid concentrations in fescue tissues but are used 1) to avoid grazing of tall fescue with increased ergot alkaloid concentrations in the late spring and summer by moving cattle to warm-season grass pasture and 2) to dilute dietary alkaloids by interseeding clovers or feeding supplements.

Key words: endophytes, fescue toxicosis, grazing, Lolium arundinaceum, Neotyphodium coenophialum, tall fescue

INTRODUCTION

Tall fescue (Lolium arundinaceum) is the predominant forage in the eastern half of the United States, particularly in the transition zone between the temperate northeast and subtropical southeast. This cool-season perennial grass is productive and persistent over a wide range of environments. These agronomic attributes resulted in fescue being extensively cultivated after the original cultivar, Kentucky 31, was released in 1943 (Buckner et al., 1977). Cattle producers in the early 1950s began observing severe lameness in cattle grazing fescue, which was linked to ergot alkaloids (Maag and Tobiska, 1956). Infection of fescue with the Epichloë typhina and, later, Neotyphodium coenophialum endophytes was first reported by Bacon et al. (1977). A grazing experiment conducted by Hoveland et al. (1983) with steers grazing fescue with low and high endophyte infections confirmed that ergot alkaloids produced by the endophyte were causal agents of fescue toxicosis.

Upon discovery of the endophyte, it appeared that challenges to cattle production on fescue could be alleviated by planting endophyte-free cultivars. Unfortunately, endophyte-free cultivars that were commercially released in the 1980s lacked persistence, and grazed stands of these cultivars rapidly deteriorated. It was apparent that the combination of beneficial agronomic traits and compromised animal production was associated with alkaloids produced by tall fescue-endophyte mutualism rather than any genetic superiority of tall fescue. As such, the grass provides intracellular
space and substrate for the endophyte to colonize and the endophyte produces secondary metabolites with biochemical properties that enhance the tolerance of the plants to abiotic and biotic stresses (Bacon, 1993; Schardl et al., 2004). The intent of this paper is to discuss the research that has led to the development of 5 management approaches that either reduce the severity of toxicosis or alleviate it altogether.

BACKGROUND

**Neotyphodium coenophialum Endophyte Alkaloids**

The endophyte produces 3 classes of alkaloids (Siegel et al., 1990): pyrrolizidines (i.e., lolines), peramine (i.e., a pyrrolopyrazine), and the ergot alkaloids (i.e., clavines, lysergic acid derivatives, and ergot alkaloids). Primary lolines produced are N-acetylloline and N-formylloline. Lolines have been indicated to enhance amine receptor activation by the ergot alkaloids. For example, elevated core body temperatures result when ergovaline/kg DM). Further, vasculature of endophyte-naive heifers was shown by Aiken et al. (2007, 2009) to be sensitive to ergot alkaloids. Using color Doppler ultrasonography, Aiken et al. (2009) showed alkaloid-induced constriction of the caudal artery to occur within 27 h of endophyte-naive heifers being fed diets containing 0.8 mg ergovaline/kg DM and within 51 h for those fed 0.4 mg ergovaline/kg DM.

Klotz et al. (2007), using a myograph, measured contractile response to ergovaline in lateral saphenous veins biopsied from endophyte-naive heifers and reported initial constriction was elicited at an ergovaline concentration of $1 \times 10^{-8} M$, and maximum contractility intensity was 69.6% of the contractile response of norepinephrine (i.e., done to normalize data), which was achieved at $1 \times 10^{-4} M$ concentration. Klotz et al. (2006) had reported from an earlier in vitro study that a greater concentration ($1 \times 10^{-4} M$) of lysergic acid was needed to elicit contraction of the lateral saphenous vein and then only a fraction of the maximal contractile response of ergovaline. In addition, Klotz et al. (2008) reported that ergonovine, ergocryptine, ergocristine, and ergocornine induced a contractile response by the lateral saphenous veins of endophyte-naive heifers at similar concentrations ($1 \times 10^{-7} M$), but the greatest maximum contraction intensity relative to norepinephrine was achieved by ergonovine (68.5%), and maximum contractility intensities were similar between ergocryptine (45.5%), ergocristine (42.9%), and ergocornine (57.2%). Although ergovaline has been demonstrated to be the most potent vasoconstrictor, Klotz et al. (2008) surmised that ergopeptines likely have additive effects on the intensity of vascular contraction, thus indicating all are likely contributors to fescue toxicosis and are of importance when considering alleviation management.

Tall fescue has been primarily utilized for cow-calf production despite the negative effects of the ergot alkaloids on calving rates and weaning weights (Paterson et al., 1995). Hoveland (1993) estimated the negative effects of the endophyte to annually cost the U.S. beef industry $354 million in reduced calf numbers and $255 million in reduced weaning weights. Adjustment to current cattle prices apparently would substantially increase this annual cost. Further, Strickland et al. (2011) postulated that with additional costs of toxic tall fescue to the equine and small-ruminant industries the total cost to the U.S. forage-based livestock industry would likely exceed $1 billion/yr. Further, Paterson et al. (1995) estimated that ADG of steers grazed on toxic tall fescue with greater than 61% of the plants infected with the endophyte can range from 0.21 to 0.62 kg/d. Poor BW gain and ill thrift of calves that graze toxic endophyte-infected tall fescue pasture have resulted in minimal use of the grass for stocker production (Hoveland, 1993).
Two additional maladies manifested by fescue toxicosis, fescue foot and fat necrosis, also add a cost to the industry, but incidences and actual impact of each are not clearly established. This is because they occur primarily in cow herds with long-term exposure to toxic endophyte-infected tall fescue and are often not reported or documented. Symptoms of fescue foot range from lameness to necrosis of hoofs, tails, or ear tips and is caused by persistent constriction of blood flow to the extremities, typically in the presence of cold air temperatures (Garner and Cornell, 1978; Cornell et al., 1982). Fat necrosis is characterized by accretion of hard fat masses within the abdominal cavity that eventually leads to severe discomfort and blockage of digesta (Hemken et al., 1984; Stuedemann et al., 1985).

**MANAGEMENT OF THE TALL FESCUE–ENDOPHYTE SYMBIOSIS**

**Grazing Management**

The endophyte has a dependence on the fescue host plant for space and substrate for growth, which provides opportunity to manage the grazing of the tall fescue–endophyte complex for controlling alkaloid toxicity of livestock. Greater ergot alkaloid concentrations in leaf sheaths than in blades can be linked to greater mycelia mass in sheaths than in blades. Elongation and growth of the endophyte are initiated from tiller meristems and exhibit extensive parallel growth in intracellular spaces within the sheath, but colonization is much lower in leaf blades and sometime does not occur (Christensen et al., 2001). Christensen et al. (2002) suggested the extent of colonization of the leaf blade was dependent on the timing that hyphae enter the developing leaf. The cells between blades and sheaths (i.e., ligular zone) lack continuous intracellular spaces and could serve as a physical barrier to hyphae entrance into the blade (Hinton and Bacon, 1985; Christensen et al., 2002). Greater mycelia mass in the sheath than in the blade actually serves in favor of the endophyte. Photosynthates from leaf blades are translocated to the sheath, where there is considerable carbohydrate accumulation and storage (MacAdam and Nelson, 2003). Therefore, the endophyte is benefited by placing high mycelia mass in the sheath, where there is abundant energy.

Bransby et al. (1988) observed ADG of steers grazing tall fescue with greater than 70% of the plants infected with the endophyte do not respond to increases in stocking rate, whereas ADG of those grazing pastures with less than 15% of the plants infected with the endophyte declined linearly with increased stocking (Fig. 1). Declines in ADG, whether linear or curvilinear, with increases in stocking rates are typical for cool- and warm-season grasses (Mott, 1960; Jones and Sandland, 1974). A lack of change in ADG as stocking increases results in steep linear increases in BW gain per hectare. Bransby et al. (1988) suggested that increased pasture utilization with increases in stocking rate decreased the emergence and selective grazing of the high-ergot-alkaloid-containing seed heads (Goff et al., 2012). This indicates that animal performance on endophyte-infected tall fescue pastures grazed with light stocking rates is primarily limited by ergot alkaloid toxicity and is limited by forage availability when grazed with heavy stocking rates. Aiken et al. (2006) evaluated the effects of stocking rate and steroidal implants on BW gain of steers grazing endophyte-infected tall fescue and found ADG to not change as stocking increased for pastures grazed by nonimplanted steers; however, ADG decreased linearly as stocking increased and forage availability decreased for implanted steers. Therefore, ADG responses by implanted steers to stocking rates were similar to the ADG responses to stocking rates reported by Bransby et al. (1988) for tall fescue pastures with low endophyte infection percentages. Aiken et al. (2006) concluded that effectiveness of the implants decreased with reductions in forage availability/nutrient supply as stocking rates increased.

![Figure 1](image-url)

**Figure 1.** Relationships of ADG (pairs of regression lines on the left side) and total BW gain/ha (pairs of regression lines on the right side) to stocking rate measured (top) by Bransby et al. (1988) for steers grazing either high-toxicity endophyte-infected or low-toxicity endophyte-infected tall fescue and (bottom) by Aiken et al. (2006) for steers with or without steroidal hormone implants (Synovex-S; 200 mg of progesterone and 20 mg of estradiol benzoate; Fort Dodge Animal Health, Fort Dodge, IA) grazing toxic endophyte-infected tall fescue. Relationships for Bransby et al. (1988) were derived from means reported in the paper.
Seed heads and stems in underutilized endophyte-infected tall fescue pastures are a toxic source of ergot alkaloids, and reductions in seed presence as utilization increases can reduce toxicity of the overall forage (Aiken et al., 2012; Goff et al., 2012). It was further reported by Belesky and Hill (1997) that frequent, intensive grazing can reduce ergot alkaloid concentrations in vegetative tillers. In this experiment, leaves and pseudostems (i.e., swirl of leaf sheaths) of uncut plants of 2 tall fescue genotypes yielded twice the ergot alkaloid concentrations of those harvested from plants cut to 5- or 10-cm heights at 7-d intervals for a 6-wk period. Similarly, Salminen and Grewal (2002) reported greater ergovaline concentrations in tall fescue plants cut biweekly than those cut weekly. Belesky and Hill (1997) suggested that tall fescue plants under frequent, intensive grazing will partition carbohydrates to regrowth, leaving less substrate available for alkaloid production by the endophyte. Another factor is that close, frequent grazing can modify plant morphology and increase leaf blade to stem ratios (Detling and Painter, 1983) and increase the proportion of leaf blades, which may reduce the toxicity of tall fescue tillers. Apparently, animal performance on lightly stocked endophyte-infected tall fescue is limited by the ergot alkaloids, and on heavily stocked fescue pastures it is limited by forage availability.

A caveat with continuous, intensive grazing of tall fescue to reduce ergot alkaloid toxicity is that tall fescue will not persist. Heavy applications of N fertilizer will be needed to negate or minimize deterioration of stands, but current high N prices are becoming cost prohibitive. Interseeding tall fescue with legumes colonized by N-fixing Rhizobia bacteria is an alternative source, but most legumes do not persist under continuous, intensive frequent grazing. Further, increasing soil N has been demonstrated in greenhouse (Lyons et al., 1986; Arechavaleta et al., 1992; Belesky and Hill, 1997) and field experiments (Belesky et al., 1988) to increase ergot alkaloid concentrations in fescue tissues. Belesky and Hill (1997) determined that rate of increase in ergot alkaloid concentration with increased soil N was greater in tissues with more water-soluble carbohydrates available to the endophyte as an energy source. It was further concluded that low water-soluble carbohydrate concentrations in frequently and closely defoliated endophyte-infected tall fescue limit ergot alkaloid concentrations regardless of soil N status. Nonetheless, having tall fescue plants maintain low concentrations of water-soluble carbohydrates likely limits production of other beneficial alkaloids and causes these plants to be more vulnerable to environmental stresses.

Low ergot alkaloid concentrations in leaf blade tissues relative to other plant parts (Rottinghaus et al., 1991) indicate that intake of ergot alkaloids could be reduced by adopting grazing management practices that maximize consumption of leaf blades. Prestidge (1993) suggested that rotational stocking systems that use rapid rotations (1 or 2 d of grazing) to increase consumption of leaf blades relative to leaf sheath could control incidence of ryegrass staggars in perennial ryegrass infected with the N. lolii endophyte. Research has not been conducted with perennial ryegrass or tall fescue to support this premise, but this grazing management approach has the potential to reduce consumption of alkaloids in tall fescue if seed head emergence is controlled (Aiken et al., 2012; Goff et al., 2012).

**Artificial Infection of Tall Fescue Cultivars with Nontoxic Endophytes**

As previously discussed, endophyte-free tall fescues lack persistence and therefore fail as an alternative to endophyte-infected tall fescue (Bouton et al., 1993). The host plant has genetic control over alkaloid production by endophytes in tall fescue (Agee and Hill, 1994) and perennial ryegrass (Easton et al., 2002), which indicates that cultivars of both grasses could be developed for low alkaloid production. Such cultivars have not yet been commercially developed for either, but a new technology has been developed that focuses on the identification and development of novel endophyte strains that do not produce ergot alkaloids while still producing the lolines and peramine alkaloids. AgResearch Ltd. (Ruakura, New Zealand) was first to patent nonergot alkaloid-producing strains of Neotyphodium coenophialum (Latch et al., 2000). Bouton et al. (2002) evaluated 5 of the strains from AgResearch in combination with 2 tall fescue cultivars, Jesup and Georgia 5. The Jesup and AR542 novel endophyte strain combination provided the greatest survival under mob grazing and was eventually commercially released as Jesup-MaxQ. Other novel endophyte tall fescues have been released since the release of Jesup-MaxQ (Phillips and Aiken, 2009).

Interactions between host plant genotype and endophyte strains on ergot alkaloid production make it prudent to conduct grazing trials to verify that there are no negative impacts when the novel endophyte–tall fescue cultivars/accessions are grazed. Experiments conducted with different livestock classes grazing novel endophyte tall fescues have, thus far, consistently reported increased BW gains and prolactin concentrations compared with those grazing toxic endophyte tall fescue and similar responses to those grazing endophyte-free tall fescue (Table 1). Experiments with steers and heifers have reported greater BW gain on novel endophyte tall fescue pasture than on toxic endophyte pastures (Parish et al., 2003; Nihsen et al., 2004; Franzluebbers and Stuedemann, 2006; Hopkins and Alison, 2006; Beck et al., 2009; Johnson et al., 2012).
Franzluebbers and Stuedemann (2006) and Johnson et al. (2012) both reported novel endophyte tall fescue pastures to have decreased carrying capacities than the toxic endophyte tall fescue pastures, but greater ADG in novel endophyte pastures compensated, resulting in pasture providing greater BW gain per hectare than toxic endophyte tall fescue pastures. Body temperatures also have been shown to be lower in cattle grazing novel endophyte-infected tall fescue pasture than in those grazing toxic endophyte pasture (Parish et al., 2003; Nihsen et al., 2004; Hopkins and Alison, 2006; Johnson et al., 2012). Nihsen et al. (2004) observed steers grazing novel endophyte-infected tall fescue (strain 4-HiMag tall fescue) to shed and maintain sleek hair coats, whereas those grazing toxic endophyte tall fescue maintained rough hair coats. Results of grazing evaluations of novel endophyte–tall fescue combinations have provided strong evidence that they are nontoxic and can be reliable in alleviating fescue toxicosis.

An advantage of wild-type endophyte-infected tall fescue is its persistence under environmental stresses, but it has not been determined if ergot alkaloids have a major role in affecting plant survival to environmental stresses. Therefore, there was early concern of the persistence of tall fescue infected with nonergot alkaloid-producing (novel) endophytes. During the development of Jesup-MaxQ, Bouton et al. (1993) interseeded small plots into bermudagrass sod of Jesup tall fescue that were either endophyte free, infected with the wild endophyte, or infected with 3 novel endophytes (i.e., AR502, AR510, and AR542). The plot area was continuously stocked for 3 yr with cattle from April to November, and stocking was varied to maintain a grazing height of 7.5 cm. After 3 yr of grazing, plant survival for the novel endophyte–tall fescue combinations was greater than the 2.3% survival percentage recorded for plants of endophyte-free Jesup tall fescue, but the 25.3% plant survival for Jesup infected with the AR542 novel endophyte was the only combination with plant survival that was statistically similar to 36.3% survival for Jesup infected with the wild-type endophyte. Hopkins and Alison (2006) found minimal losses of Georgia-5 MaxQ tall fescue plants after 4 yr of continuous grazing by steers in the fall and spring. Stocking rates during the spring averaged 1,500 kg BW/ha. At the conclusion of a 6-yr grazing experiment, Franzluebbers et al. (2009) reported 73% basal cover for Jesup MaxQ, which was similar to wild-type Jesup (74%) and greater than for endophyte-free Jesup (67%).

Novel endophyte-infected tall fescue pastures have been shown to persist under lax grazing management, but low inputs of management cannot be assumed with novel endophyte tall fescue. The major concern with the survival of novel endophyte-infected tall fescue is during the summer slump in growth of tall fescue. In toxic endophyte-infected tall fescue, the decline in summer growth of forage corresponds to a decline of forage intake as core body temperatures increase from persistent, ergot alkaloid-induced vasoconstriction. Grazing experiments conducted in the spring (Parish et al., 2003) and late spring and summer (Howard et al., 1992) reported that cattle grazing toxic endophyte-infected tall fescue pastures spent more time idling and less time grazing than those on nontoxic pastures. Dry matter intake of steers fed diets with toxic tall fescue seed and held at a constant 32°C was 22% less than those held at 22°C (Aldrich et al., 1993). For a grazing experiment conducted in April, May, and June, Parish et al. (2003) reported 43% greater intake by steers grazing endophyte-free and Jesup-MaxQ tall fescue than those grazing toxic endophyte-infected Jesup. Howard et al. (1992) suggested that cattle grazing toxic endophyte-infected tall fescue pasture may compensate for decreased

### Table 1. Differences in ADG and serum prolactin concentrations for different livestock classes between novel endophyte tall fescue and control treatments (toxic, endophyte, and endophyte-free tall fescue)

<table>
<thead>
<tr>
<th>Livestock/class</th>
<th>Novel endophyte/ Tall fescue cultivar</th>
<th>ADG, kg</th>
<th>Difference from control treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Toxic endophyte</td>
</tr>
<tr>
<td>Steers</td>
<td>AR542/Jesup</td>
<td>+0.35²</td>
<td>129</td>
</tr>
<tr>
<td>Postpartum cows</td>
<td>AR542/Jesup</td>
<td>+0.17²</td>
<td>+102</td>
</tr>
<tr>
<td>Suckling calves</td>
<td>AR542/Jesup</td>
<td>+0.16²</td>
<td>+300</td>
</tr>
<tr>
<td>Lambs</td>
<td>AR542/Jesup</td>
<td>+0.06²</td>
<td>+292</td>
</tr>
<tr>
<td>Heifers</td>
<td>AR542/Jesup</td>
<td>+0.34²</td>
<td>NS</td>
</tr>
<tr>
<td>Steers</td>
<td>Strain 4/HiMag</td>
<td>+0.26²</td>
<td>+138</td>
</tr>
<tr>
<td>Steers</td>
<td>AR542-Georgia 5</td>
<td>+0.38²</td>
<td>+6</td>
</tr>
<tr>
<td>Steers</td>
<td>BarOptima PLUS E-34</td>
<td>+0.57²</td>
<td>+126</td>
</tr>
<tr>
<td>Steers</td>
<td>AR584-KYFA9301</td>
<td>+0.18²</td>
<td>+125</td>
</tr>
</tbody>
</table>

¹Results are for those collected during spring and early summer grazing.
²Toxic control was toxic endophyte-infected Jesup tall fescue.
³No significant difference between novel endophyte-infested and endophyte-free tall fescues.
⁴Toxic control was toxic endophyte Kentucky 31 tall fescue.
DMI during warm, daylight hours by increasing grazing during cooler evening hours; however, McClanahan et al. (2008) reported a negative correlation (−0.76) between mean ambient temperature and frequency of grazing in the early evening hours (1830 to 2200 h) for steers grazing toxic, endophyte-infected tall fescue. This agrees with the results of Johnson et al. (2012), who reported greater carrying capacities for toxic endophyte Kentucky 31 pastures than endophyte-free and 2 novel endophyte tall fescue (Jesup-MaxQ and AR584-KYFA9301) pastures that were grazed during the spring and early summer. Greater carrying capacities were not generated on toxic Kentucky 31 pastures, however, until after the midpoint of the grazing seasons, when warmer ambient temperatures occurred. Good grazing management practices will be necessary for novel endophyte tall fescues to persist if they are grazed during the late spring and summer.

**Suppression of Seed Heads**

Seed heads of tall fescue are selectively grazed by cattle and horses (Aiken et al., 1993), which can be problematic because ergot alkaloid concentrations are greater in seed heads than leaf blades and sheaths (Rottinghaus et al., 1991). Rottinghaus et al. (1991) determined that ergovaline concentrations in seed heads were 3- to 10-fold greater than in leaf blades and stems with leaf sheaths. Goff et al. (2012) observed greatest consumption of seed heads by steers between anthesis and milk stages of seed development. By the dough stage, 78.8% of the seed heads had been grazed. In vitro organic matter digestibility of grazed seed heads was greater than 62%, and ergovaline disappearance during in vitro digestion was nearly 100%. Seed heads represent a highly toxic source of ergot alkaloids that are selectively grazed when they are immature and moderately digestible.

There was considerable research conducted in the 1980s on the plant growth regulator mefluidide because of its ability to delay maturity of cool-season grasses by suppressing seed head emergence (Sheaffer and Marten, 1986; Wimer et al., 1986). Application of mefluidide to tall fescue was demonstrated to enhance forage quality (Robb et al., 1982; McCarty et al., 1985; Sheaffer and Marten, 1986). Turner et al. (1990a) reported steers grazing toxic endophyte-infected tall fescue pastures treated with mefluidide as having over 20% greater ADG than those grazing untreated pastures, and heifers grazing mefluidide treated pastures in a separate experiment had 47% greater OM intake than those grazing untreated pastures. Although the chemical showed potential for improving animal performance on endophyte-infected tall fescue, the plant growth regulator was restricted from use on pastures (PBI/Gordon Corp., 2010).

Metsulfuron specifically suppresses seed head emergence in tall fescue (Aiken et al., 2012) and is used in grazed pastures (Chaparral, DowAgrosciences, Indianapolis, IN, and Cimarron, E. I. du Pont de Nemours and Co., Wilmington, DE). Aiken et al. (2012) reported that steers grazing toxic endophyte tall fescue treated with Chaparral herbicide had 39% greater ADG, 2-fold greater serum prolactin, and reduced rectal temperatures as compared with those on untreated pastures. The increased BW gain was partially attributed to increases in CP, water-soluble carbohydrates, and in vitro DM digestibility with seed head suppression. Similarly, Turner et al. (1990b) found greater CP and in vitro OM digestibility in mefluidide-treated toxic endophyte tall fescue than in untreated pastures. Reduced body temperatures and increased prolactin concentrations in steers grazing Chaparral-treated toxic tall fescue (Aiken et al., 2012) indicate there is some mitigation of fescue toxicosis. Although seed head suppression of toxic endophyte tall fescue appears to enhance cattle performance and well-being, it also reduces forage availability by as much as 51% (Turner et al., 1990a), but research is needed to determine how much of the decline in availability is attributed to a reduction in the presence of stems and seed heads, greater forage intake (Turner et al., 1990a), or a direct negative effect on vegetative growth rates.

**Avoidance of Ergot Alkaloids**

Another management approach is to rotate cattle in the mid to late spring to warm-season grass pastures. Although this management practice does not manipulate the endophyte–tall fescue symbiosis, it uses the seasonality of ergot alkaloid production and accumulation to avoid those time periods when alkaloid concentrations are high and seed heads are present. Ergot alkaloid concentrations in whole plants increase as reproductive development advances during the spring (Rogers et al., 2011). The management approach, therefore, can eliminate alkaloid consumption when highly toxic seed heads are present in the stand (Goff et al., 2012) and when cattle are most vulnerable to severe heat stress and a depression in performance. Rotating cattle from tall fescue to warm-season grass pasture during the warm season also provides grazing during active growth of the warm-season grass when there is a slump in tall fescue growth (Roberts and Andrae, 2004).

Aiken and Piper (1999) grazed steers during the spring on toxic endophyte tall fescue with 2 replications of 4 stocking rates. In mid spring, 1 replication was rotated to eastern gamagrass (Tripsacum dactyloides L.), and the other replication remained on tall fescue and was supplemented with a 1:1 mixture of broiler litter and corn. At 28 d after being rotated to eastern gama grass,
the rotated steers had 2-fold greater serum prolactin concentrations than those on tall fescue. A greater percentage of steers remaining on tall fescue pasture had rough hair at the end of summer grazing, and ADG of these steers was less than those on the 2 lighter stocking rates (3.0 and 4.0 steers/ha) but not the 2 heavier rates (5.0 and 6.0 steers/ha). Kallenbach et al. (2012) found inconsistency across years in an enhancement of ADG by preferentially rotating steers in the spring and summer from toxic endophyte tall fescue to bermudagrass as compared with those that remained on rotationally stocked tall fescue. Similarity between the 2 treatments in 2 of the 3 yr of the experiment was attributed to less in vitro DM digestibility of the bermudagrass and good growth of tall fescue from above-average rainfall during the 2 yr of greater ADG on spring- and summer-grazed tall fescue. Scaglia et al. (2008) rotated cows during the summer from toxic endophyte-infected tall fescue toswitchgrass (Panicum virgatum L.) pastures and found no differences in BW or BCS between these cows and those that remained on a toxic endophyte tall fescue–clover mixed pasture.

Inconsistency in results of experiments that have evaluated rotation of cattle from toxic endophyte-infected tall fescue to warm-season perennial grass pastures likely is related to environmental conditions. A benefit from rotating cattle to warm-season perennial grass pastures is likely realized with warmer, drier summers when incidence of ergot alkaloid-induced heat stress is greater and there is minimal growth of tall fescue.

**Dilution of Ergot Alkaloids**

Interseeding toxic endophyte-infected tall fescue with clovers has long been recommended for the purpose of diluting ergot alkaloids in ruminant diets (Ball, 1984; Roberts and Andrae, 2004). Greater steer ADG with mixtures of toxic endophyte tall fescue and clover than with monocultures of toxic endophyte tall fescue has been demonstrated (Hoveland et al., 1981; McMurphy et al., 1990). Hoveland et al. (1981) reported greater ADG and BW gain per hectare for Ladino white clover–tall fescue pastures (0.74 kg/d and 504 kg/ha, respectively) than for pastures of tall fescue (0.37 kg/d and 293 kg/ha, respectively) during spring grazing. Similarly, McMurphy et al. (1990) showed red clover interseeded into tall fescue to increase ADG by 0.2 kg.

Although interseeding legumes into toxic endophyte tall fescue indicates an improvement in animal performance, experiments have shown the benefit from interseeding clovers or other botanical components may be linked to diet quality rather than mitigation of fescue toxicosis by dilution of ergot alkaloids in the diet. Fribourg et al. (1991) reported detrimental effects of ergot alkaloids on ADG, serum prolactin, hair coat scores, and rectal temperatures as endophyte infection of plants in the stand increased from 22% to 35% and with minimal differences between 35%, 60%, and 81% infection. Goetsch et al. (1987b) fed clover hay at 0.73% of BW to dairy steers in combination with ad libitum quantities of either toxic endophyte or endophyte-free tall fescue hay and found steers consuming the toxic endophyte hay had lower DMI and serum prolactin. In a second experiment conducted by these researchers, steers were fed hays with increasing percentages of toxic endophyte tall fescue hay in a mixture with endophyte-free fescue hay. Dry matter intake decreased linearly with dietary percentage of toxic endophyte hay, with the 25% dietary level of toxic hay causing a decline in DMI relative to the 0% dietary level. There was no difference in serum prolactin concentrations in steers consuming the 0% and 25% dietary levels of toxic hay, but prolactin concentrations declined as dietary levels increased above 25%.

Supplementation with grains or coproduct feeds has been demonstrated to have results similar to supplementation with nontoxic forages. Goetsch et al. (1987a) and Stokes et al. (1988) both reported increases of total OM intake and digestion in dairy steers as corn supplementation increased from 0.5% to 1.0% of DMI, but there was no difference in serum prolactin concentrations between these treatments and the toxic tall fescue control. Stokes et al. (1988) observed dairy steers fed for ad libitum intake toxic endophyte tall fescue hay and corn at 0.65% of BW had greater ADG than those fed solely toxic endophyte tall fescue hay. Richards et al. (2006) reported soybean hulls fed at 0.60% of BW, on an OM basis, decreased OM intake of green chop toxic endophyte tall fescue by 14% but increased total OM intake and digestion. Carter et al. (2010) reported soybean hulls fed to steers grazing toxic endophyte-infected tall fescue in the spring at a rate of 2.3 kg/(steer·d) on an as-fed basis provided a 32% increase in ADG over steers on control pastures. Further, steers fed soybean hulls had more than 2-fold greater serum prolactin concentrations, and a greater percentage of these steers had sleek hair coats at the conclusion of grazing. It is plausible that fiber constituents in soybean hulls could bind ergot alkaloids in the rumen to reduce ruminal and intestinal absorption. Conversely, however, Aiken et al. (2008) also observed an increase in ADG of steers grazing toxic endophyte tall fescue in the summer and fed soybean hulls at a rate of 2.3 kg/(steer·d) on an as-fed basis, but there were no differences in serum prolactin or hair coat ratings between treatments with and without soybean hulls. One possible explanation for the different hair coat ratings and serum prolactin concentrations in the last 2 studies could be that the steers may have had carryover of ergot alkaloids in their tissues (i.e., because of bioaccumulation; Klotz et al., 2009) from spring grazing before initiation of the experiment conducted during the summer.
Interseeding clovers or supplementation with grains or coproduct feeds may primarily improve the diet quality of cattle grazing toxic endophyte tall fescue pasture to benefit animal performance. As previously discussed, endophyte-naive cattle have exhibited a vasoconstrictive response to ergot alkaloids within 51 h after initial daily feeding of diets containing 0.4 g ergovaline plus its epimer, ergovalalnine (Aiken et al., 2009). Furthermore, the affinities of ergot alkaloids to biogenic amine receptors are strong and appear to cause the alkaloids to bioaccumulate in the vasculature (Klotz et al., 2009, 2010). Ergot alkaloid accumulation in subcutaneous adipose tissues (Realini et al., 2005) could serve as a reservoir for the alkaloids but also could be mobilized to the vasculature. Therefore, even small dietary concentrations of ergot alkaloids may potentially bioaccumulate over time in tissues to concentrations that can induce toxicosis symptoms.

SUMMARY AND CONCLUSIONS

Agronomic traits of tall fescue attributed to the toxic endophyte have resulted in this endophyte-grass complex being widely utilized in a large region of the United States, but ergot alkaloids produced by the endophyte induce a toxicosis that adversely affects cattle performance and well-being. Management approaches can be used to improve cattle production on toxic endophyte tall fescue and mitigate or alleviate the symptoms of toxicosis. Continuous, intensive grazing of toxic endophyte tall fescue can reduce alkaloid toxicity of the tall fescue, but high inputs of fertilizer and weed control will be necessary for pastures to be sustainable. Recent development of tall fescue cultivars artificially infected with novel endophytes that do not produce ergot alkaloids is the only technology currently available to alleviate fescue toxicosis, but because herbivory by cattle is not impeded by ergot alkaloids, grazing management must be modified during periods of low forage growth. The highly toxic seed heads that are readily grazed by cattle can be suppressed with metsulfuron containing herbicides to improve animal performance, but grazing management will be needed to accommodate for a reduction in forage production. Vulnerability to severe heat stress also can be avoided by moving cattle to warm-season grass pastures during the late spring and summer, but there may not be a benefit to animal performance if low-quality warm-season grasses are used or if they are overgrazed. Dilution of ergot alkaloids by interseeding legumes or feeding supplements has been recommended. Although this management approach can benefit animal performance, the sensitivity of cattle to ergot alkaloids and bioaccumulation of the alkaloids in cattle tissues appear to limit the effectiveness of ergot alkaloid dilution in alleviating toxicosis.

These management approaches provide options to cattle producers in managing around fescue toxicosis. Other technologies and approaches could also be developed in the future as more basic research is conducted to better understand effects of ergot alkaloids at the cellular and molecular levels.

LITERATURE CITED

Managing endophyte-infected tall fescue


