A Review of the Agronomic Characteristics of Endophyte-Free and Endophyte-Infected Tall Fescue

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Abstract. Agronomic differences between endophyte- (*Acremonium coenophialum* Morgan Jones and Gams) free and endophyte-infected tall fescue (*Festuca arundinacea* Schreb.) exist, and should be considered when implementing a management strategy. Although dry matter yield of tall fescue does not generally appear to be influenced by endophyte infection status, endophyte infection has been shown to improve seedling performance and survival, is associated with insect and nematode resistance, drought resistance, improved nitrogen assimilation, and higher seed set. Considering all biologically valuable characters of the endophyte-tall fescue relationship, survival of endophyte-infected tall fescue is probably better than that of endophyte-free tall fescue, especially in drought- or heat-stressed environments. Despite problems which growers have reported in establishing stands of endophyte-free tall fescue varieties, there is still a decided advantage to seeding endophyte-free tall fescue because of improved livestock performance. However, greater attention to management is needed, particularly during the establishment year. Good seedbed preparation, including fertility improvements, should be stressed for endophyte-free tall fescue. Since endophyte-free tall fescue seedlings are not as vigorous as endophyte-infected tall fescue seedlings, using other grasses as nurse crops, or seeding with clovers, is not recommended when establishing new stands. Environmental or imposed stress on newly established endophyte-free tall fescue stands should be avoided by selecting optimum planting dates, and limiting livestock access. Top growth should not be grazed or clipped shorter than 3–4 in. (7–10 cm) during the first year of growth.

Introduction

Since the release of "Kentucky 31" tall fescue (*Festuca arundinacea* Schreb.) in 1943 (Fergus and Buckner, 1972), tall fescue has become the most widely grown cool-season forage grass in the southeastern quarter of the U.S.A., occupying an estimated 35 million A (14 million ha) (Buckner and Bush, 1979). The rapid and extensive adoption of this species was due to its agronomic characteristics, including ease of establishment, a long grazing season, tolerance of low management inputs, and broad adaptation to soil types and geographic areas (Burns and Chamblee, 1979). Livestock productivity on this species, however, has often been unexplainably poor. The cause of this poor livestock performance has been discovered recently, and is due to the infection of tall fescue with an endophytic fungus, *Acremonium coenophialum* Morgan-Jones and Gams (Bacon et al., 1977).

The high productivity of livestock grazing endophyte-free tall fescue compared to endophyte-infected tall fescue is well documented (Stuedemann and Hoveland, 1988). However, the agronomic differences between endophyte-free and endophyte-infected tall fescue are not completely or widely understood. Such differences do exist, and although management decisions may not be based solely on these differences, current knowledge about them should be considered when implementing a management strategy for tall fescue.

Most tall fescue pastures established prior to 1987 are endophyte-infected (Shelby and Dalrymple, 1987). The source of endophyte infection for these pastures was probably the original collection

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Table 1. Forage quality of endophyte-infected and endophyte-free field-grown Kentucky 31 tall fescue

	IVDMD (%)	NDF (%)	ADF (%)	Crude Protein (%)
Kentucky 31 (+)[a]	57	64	32	17
Kentucky 31 (−)	57	65	32	16

[a] (+) = endophyte-infected and (−) = endophyte-free.
Adapted from Carlson and Umbaugh, 1988; and Bush and Burrus, 1988.

Table 2. Total seasonal yield of endophyte-infected and endophyte-free Kentucky 31 tall fescue in the field (ton/A/yr)[a]

	Tallassee, AL 1978–1980	Lexington, KY 1983–1986	Ames, IA 1988
Kentucky 31 (+)[b]	4.2	2.9	3.3
Kentucky 31 (−)	4.3	2.9	3.3

[a] T/A × 2.75 = t/ha.
[b] (+) = endophyte-infected and (−) = endophyte-free.
Adapted from Pedersen et al., 1982; Burrus et al., 1987; and Carlson and Umbaugh, 1988.

site of Kentucky 31, since seed collected from that site were highly endophyte-infected. However, most currently marketed forage tall fescue cultivars are endophyte-free. If elimination of the endophyte results in agronomic characteristics different from those which have caused tall fescue to become the most widely grown forage grass in the U.S.A., it could greatly impact the value of the species.

Forage Quality and Quantity

Although endophyte infection of tall fescue affects grazing animal performance, it does not appear to affect forage quality as measured by conventional nutritive indices. Endophyte status did not affect in vitro dry matter disappearance (Carlson and Umbaugh, 1988), neutral detergent fiber, acid detergent fiber, or crude protein (Bush and Burrus, 1988) in-field grown samples of Kentucky 31 (Table 1). Laboratory assessments of tall fescue forage quality, regardless of endophyte status, are comparable to many other cool-season perennial grasses. In vitro dry matter disappearance is comparable to that of orchardgrass (*Dactylis glomerata* L.) (Carlson and Umbaugh, 1988). Crude protein content is comparable to smooth brome (*Bromus inermis* Lyss.), orchardgrass, and reed canarygrass (*Phalaris arundinacea* L.) (Johnson and Nichols, 1969).

In general, dry matter yield of tall fescue does not appear to be influenced by the endophyte infection status (Burrus et al., 1987; Carlson and Umbaugh, 1988; Pedersen et al., 1982) (Table 2). However, as will be described later, tall fescue dry matter yields are enhanced by endophyte infection under certain conditions.

Table 3. Seedling yield of endophyte-infected and endophyte-free Kentucky 31 and Georgia Jesup in the field (lb/A)[a]

	1987	1988
Kentucky 31 (+)[b]	316	440
Kentucky 31 (−)	185	274
Georgia Jesup (+)	422	603
Georgia Jesup (−)	279	364

[a] lb/A × 1.1 = kg/ha.
[b] (+) = endophyte-infected and (−) = endophyte-free.
Adapted from Pedersen and Burrus, 1989.

Biological Value of Endophyte Relationship

Endophyte infection status can affect seedling growth. In a growth chamber study (Clay, 1987), endophyte-infected tall fescue had higher germination rates than endophyte-free seeds at 4 through 22 days post seeding, and greater tiller number and dry weight at 10 and 14 weeks postseeding. More recent field data has confirmed that endophyte infection improves seedling performance. Pedersen and Burrus (1989) showed that two endophyte-infected tall fescue lines had nearly doubled the dry matter yields at three-months postseeding than the same lines when endophyte-free (Table 3). However, other endophyte-free lines had dry matter yields equal to or greater than either of the endophyte-infected lines in that study.

Endophyte infection status may also affect seedling survival. In a sod seeding experiment, endophyte-infected tall fescue had twice the number of surviving plants, compared to endophyte-free plants of the same genetic line, four months after seeding (Bouton and Burton, 1988). Although insufficient evidence was presented to establish a cause and effect relationship, it was observed that seedlings of the endophyte-free tall fescue had been defoliated by an unidentified insect.

Insect resistance due to endophyte infection in tall fescue has not yet been well documented in the field. However, the lack of insect damage in endophyte-infected tall fescue in the field, and endophyte-induced insect resistance in the laboratory, suggests such a relationship (Bacon and Siegel, 1988). Endophyte-induced insect resistance has been documented in the laboratory or the greenhouse for the fall armyworm (*Spodoptera frugi-*

Table 4. Effect of endophyte infection of Kentucky 31 on soil nematode populations in the field (number/100 cc soil)

	Pratylenchus	Tylenchorhynchus
Kentucky 31 (+)[a]	2	76
Kentucky 31 (−)	224	306

[a] (+) = endophyte-infected and (−) = endophyte-free.
Adapted from West et al., 1988.

Table 5. Effect of endophyte infection of Kentucky 31 on evaporative cooling of the canopy and dry matter yield in the field

	Evaporative cooling	Yield
	°C[a]	lb/A[b]
Kentucky 31 (+)[c]	−0.2	892
Kentucky 31 (−)	0.8	811

[a] °F = 1.8 × °C + 32.
[b] lb/A × 1.1 = kg/ha.
[c] (+) = endophyte-infected and (−) = endophyte-free.
Adapted from West et al., 1988.

perda J.E. Smith) (Clay et al., 1985), Argentine stem weevil (*Listronotus bonariensis* Kuschell) (Barker et al., 1983), oat bird cherry aphid (*Rhopalosiphum padi* L.), greenbug (*Schizaphis graminum* Rondani), and large milkweed bug (*Oncopeltus fasciatus* Dallas) (Siegel et al., 1985). If increased insect susceptibility is a characteristic of endophyte-free tall fescue, the greatest damage may occur on seedlings in no-till or sod seeding situations.

The presence of plant parasitic nematodes has been associated with decreased stand persistence in tall fescue, presumably due to root pruning and increased drought susceptibility. *Hopolaimus galeatus* (Cobb) Thorne, *Telenchorhynchus claytonia* Steiner, and *Paratrichodorus christiei* (Allen) were identified as potentially damaging species at a single site in Alabama (Hoveland et al., 1975). Nematode surveys of many tall fescue pastures throughout Alabama added *Helicotylenchus* spp. and *Xiphinema* spp. to the list of nematodes potentially damaging to tall fescue (Pedersen and Rodriguez-Kabana, 1984). Greenhouse studies showed that endophyte infection in tall fescue imparted resistance to *Helicotylenchus* spp. and *Paratrichodorus* spp. (Pedersen et al., 1988). Recent field research has verified endophyte-induced nematode resistance in tall fescue. Significantly fewer *Pratylenchus scribneri* Steiner and *Tylenchorhynchus acutus* Allen were found in endophyte-infected than endophyte-free tall fescue in Arkansas (Table 4) (West et al., 1988).

Endophyte infection has also been associated with morphological and physiological drought resistance mechanisms in tall fescue. Endophyte infection was shown to decrease stomatal aperture and decrease gas exchange in tall fescue clones. It was suggested that these factors could contribute to drought resistance (Belesky et al., 1987). A recent greenhouse study has confirmed the above on a limited gene base (Arachevaleta et al., 1989). In a single clonal line, 100% of endophyte-infected plants survived 40 days of severe drought stress, while only 25% of endophyte-free plants survived. Under moderate drought stress the same plants were observed to exhibit leaf roll when endophyte-infected, but not when endophyte-free. The endophyte-infected plants were also observed to have thicker, narrower leaves, which would present less surface area for evaporation. In the Arkansas study (West et al., 1988), decreased evaporative cooling and increased dry matter yields were associated with endophyte infection of tall fescue in the field (Table 5), especially under drought conditions.

Two other areas of the endophyte-tall fescue relationship show potential biological value, but have not been adequately confirmed in the field to date. First, nitrogen assimilation has been demonstrated to be more efficient in endophyte-infected plants (Bacon et al., 1986; Lyons et al., 1986). Increased yield response to nitrogen fertilization associated with endophyte infection has been observed in a single clone in the greenhouse (Archevaleta et al., 1989), but extrapolation to heterogeneous populations in the field is premature.

Secondly, differential seed set in endophyte-infected vs. endophyte-free tall fescue has been documented in the field at one location in Louisiana. Endophyte-infected Kentucky 31 had 44% filled seeds while endophyte-free Kentucky 31 had 19% filled seeds (Clay, 1987). If this response to endophyte infection occurs in mixed populations (endophyte-infected and endophyte-free plants), and if natural reseeding is significant, gradual shifts in endophyte infection levels could occur within a population.

When all biologically valuable (to tall fescue) characteristics of the endophyte-tall fescue relationship are considered jointly, improved survival of endophyte-infected tall fescue is probable, especially in drought or heat stressed environments. In environments where tall fescue is well adapted, differences in stand survival may not occur (Table 6) (Burrus et al., 1987). However, at least three field studies at droughty, high temperature sites outside of the normal area of adaptation of tall fescue have provided evidence of improved tall fescue stand

Table 6. Effect of endophyte infection of Kentucky 31 and Georgia 5 tall fescue on stand persistence in the field

	Years' post seeding (% Basal ground cover)	
	1	2
In Kentucky		
Kentucky 31 (+)[a]	—	85
Kentucky 31 (−)	—	90
In Louisiana		
Kentucky 31 (+)	98	82
Kentucky 31 (−)	88	73
Georgia 5 (+)	94	89
Georgia 5 (−)	72	48

[a] (+) = endophyte-infected and (−) = endophyte-free.
Adapted from Joost, 1988; and Burrus et al., 1987.

survival due to endophyte infection. At Americus, in south Georgia, nearly all plants of endophyte-free lines died by the end of the first year of production, while endophyte-infected lines still exhibited good stands (Bouton and Burton, 1988). Near Baton Rouge, Louisiana, basal ground cover of endophyte-free lines decreased more rapidly than the same endophyte-infected lines (Table 6) (Joost, 1988). Near Dallas, Texas, endophyte-infected Kenhy persisted under pasture conditions, while endophyte-free Kenhy suffered severe stand loss in three years (Read and Camp, 1986).

Establishing New Pastures

Despite biological advantages associated with endophyte infection in tall fescue, and numerous farmer-reported endophyte-free tall fescue establishment failures, it can still make good sense to utilize endophyte-free tall fescue in new seedings. When endophyte-free tall fescue is used, grazing livestock performance is greatly improved, and greater profits should follow. However, greater attention to management is needed, especially during stand establishment. The primary steps involved in conversion from endophyte-infected to endophyte-free tall fescue pastures are (1) destroy the old stand, (2) prepare the seedbed, (3) plant seed of an endophyte-free variety, (4) restrict grazing of seedlings, (5) do not allow heavy utilization until after one year.

Destruction of a stand of endophyte-infected tall fescue, if present, must be complete and must be accomplished sufficiently in advance of reestablishment to prevent contamination by endophyte-infected volunteer seedlings. Reestablishment should not be attempted where seedheads were not prevented from forming during the preceding 12 months (Fribourg et al., 1988). Either cultural or chemical destruction of an existing endophyte-infected stand can be effective.

Where possible, the best way to destroy an old tall fescue field is to grow a crop such as corn (*Zea mays* L.) in that field for one to two years. If an early maturing variety is used, the crop can be harvested prior to tall fescue seeding, providing cash return for the field that year. Since it is usually difficult to kill all of the tall fescue with tillage alone, some chemical control of the tall fescue is often necessary in either conventional or no-tillage rotation systems. However, care must be exercised in herbicide selection to minimize toxic residue at the time of reseeding (Lacefield and Evans, 1986). In no-tillage corn rotations Gramoxone Super (1,1′-dimethyl-4,4′-bipyridinium ion) or Roundup [N-(phosphonomethyl)glycine] are recommended for control of the tall fescue sod (Green and Martin, 1987).

Where the planting of row crops is not feasible because of erosion hazard, or other factors, chemical kill of endophyte-infected tall fescue followed by no-till seeding of endophyte-free tall fescue can be effective. Complete destruction of the endophyte-infected stand may be difficult to obtain. For best results, the endophyte-infected tall fescue must be actively growing. Complete coverage of the tall fescue is essential, so spray equipment must be adjusted so that spray will overlap above the top of the vegetation. Roundup should be applied in the fall at least seven days before reseeding when tall fescue is 4–8 in. (10–20 cm) tall. Gramoxone Super should be applied as two separate applications. The first application should be made when tall fescue is no more than 4 in. (10 cm) tall. The second application should be applied to regrowth, usually 10–21 days after the first application. Reseeding should not be initiated if any green vegetation is present (Green and Martin, 1987).

Seeding operations must ensure good seed to soil contact, and must allow placement of the endophyte-free tall fescue seed ¼ to ½ in. (6–13 mm) deep. This is critical in no-tillage establishment, as well as conventional tillage establishment. Good seedbed preparation should be stressed for endophyte-free tall fescue establishment because of the slower growth of seedlings when compared to endophyte-infected tall fescue. Although good seedbed preparation may be one of the simplest management requirements for successful establishment of endophyte-free tall fescue, failure to pre-

Table 7. Characteristics of tall fescue cultivars

Cultivar	Selection criteria
Kentucky 31	Good fall growth
Kenhy	Vigor, soft lax leaves, high forage moisture during drought stress
Forager	High herbage yield, vigor, good persistence
AU Triumph	High winter yield, open sod, erect growth
Johnstone	Low perloline, improved succulence and digestibility during summer
Martin	High seed and herbage yield, high magnesium content
Mozark	High seed and herbage yield, good animal performance
Safe	Vigorous seedlings and mature plants, pasture quality, drought tolerance, winter hardiness, and disease resistance

Adapted from Pedersen and Sleper, 1988.

pare adequate seedbeds, combined with poor soil moisture conditions, appear to be responsible for many of the reported establishment failures. Fertilizing and liming to soil test recommendations prior to seeding is also essential. Many old pasture sites are low in fertility and could result in poor seedling growth.

Selection of an endophyte-free tall fescue cultivar should be based on the characteristics of the variety (Table 7), and performance data for the region in which it is to be established. To date, few endophyte-free cultivars have been developed from endophyte-free genetic stock. Most were selected when endophyte-infected, and the endophyte was subsequently eliminated from seed stocks (Pedersen and Sleper, 1988). Since we now recognize that endophyte infection (or lack of it) affects tall fescue performance, any performance data must be verified as being for the cultivar in the endophyte-free condition.

Select endophyte-*free* seed, or seed with the lowest possible endophyte infection level. Based on many of the factors discussed in the biological value section above, endophyte-infected tall fescue plants would appear to have a competitive advantage over endophyte-free plants in a mixed population. In fact, 10 years of data from research pastures in Alabama indicate that endophyte-free pastures tend to remain endophyte-free, but that moderately infected pastures tend to increase in endophyte infection over time, at a rate of approximately 2% per year (Shelby and Dalrymple, 1988).

Environmental or imposed stress on newly established endophyte-free tall fescue stands should be avoided. Assuming that adequate moisture is present, endophyte-free tall fescue should be seeded as early in the fall as possible to allow maximum growth before winter. Spring seeding can be successful in some areas, but the risk of summer drought and substantial weed competition is high. Spring seeding in the extreme southern portion of fescue range of adaptation should be avoided. Once established, livestock access should be limited. Whether cut or grazed, defoliation during the first year of growth should leave at least a 3–4 in. (7–10 cm) stubble.

Interseeding legumes with tall fescue at planting, or into existing tall fescue sods, has been recommended for some time to improve animal performance (Taylor et al., 1979). Although interseeding legumes into established endophyte-free tall fescue pastures is still a good management practice, it involves some risk if clover is planted with endophyte-free tall fescue during establishment. Since endophyte-free tall fescue seedlings may grow more slowly than endophyte-infected tall fescue, decreased competitive ability of the tall fescue is likely. In pastures seeded in Tennessee, clover increased and tall fescue decreased over time for endophyte-free tall fescue, while tall fescue increased and clover decreased over time for endophyte-infected tall fescue (Fribourg and McLaren, 1987). For similar reasons, seeding endophyte-free tall fescue with "nurse-crops" such as annual ryegrass (*Lolium multiflorum* Lam.) or small grains is not recommended.

Pasture Management

Few failures of mature endophyte-free tall fescue pastures have been reported. However, based on the reports of decreased drought tolerance and potential reduced pest resistance, it appears wise to avoid imposing stress on such pastures by overgrazing. Cattle should be allowed to graze the pastures no closer than 3–4 in. (7–10 cm) and ungrazed pastures should be harvested as hay. Added attention should be given to monitoring pasture condition since it is a commonly held belief that cattle will more readily consume endophyte-free tall fescue. Periodic soil testing should be done and fertility maintained accordingly. Overgrazing should be avoided, especially when approaching the hot, dry summer season (Pedersen and Lacefield, 1989).

Economics of Replacing Endophyte-Infected Pastures

Where new pastures are being established, the difference in cost between establishing endophyte-in-

Table 8. Cost of replacing an endophyte-infected tall fescue pasture with endophyte-free tall fescue

Item	Cost/A[a]
Endophyte-free tall fescue seed	$20
Herbicide	20
Equipment	18
Fertilizer	25
Lime	20
Total	$103

[a] Cost/ha = Cost/A × 2.47.
Adapted from Burns, 1987.

fected tall fescue and endophyte-free tall fescue is the cost of the seed. Currently, common tall fescue (assumed to be endophyte-infected) is retailing at $0.70/lb ($1.54/kg). Endophyte-free varieties average about $1.25/lb. If seeding rate is 20 lb/A (22 kg/ha), the increased cost for establishing endophyte-free tall fescue is about $11/A ($27/ha).

Where old pastures are being replaced, cost is much more difficult to estimate because of numerous variables. An estimate of $103/A was calculated (Table 8) using data for no-till chemical-kill replacement in Tennessee (Burns, 1987). Other cost estimates for pasture replacement with endophyte-free tall fescue range from $70 to $150/A (Trimble, 1986).

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