CHAPTER 7

Endophytes—Good and Bad

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Endophytes are microorganisms, typically fungi or bacteria, that live inside a plant during part or all of their life cycle. Many plants in nature contain endophytes. In agriculture, fungi belonging to the genus *Neotyphodium* are well known for their existence in *Festuca* and *Lolium* grasses, such as the fescues and ryegrasses. The good news about these endophytes is that they often impart benefits to host grasses by aiding survival during stress. The bad news is that they produce toxins that are deleterious to livestock consuming these grasses. Endophytes and their plants can be managed to reduce the bad news for livestock and to exploit the endophyte benefits for plant vigor and persistence.

Figure 1. Hyphae of the endophyte *Neotyphodium coenophialum* in a tall fescue leaf sheath. (PHOTO BY E.C. BERNARD)

The biology of the endophyte-plant association

The relationship between the host plant and *Neotyphodium* endophytes is a mutualistic symbiosis, in that both organisms benefit from the association. The plant provides a home for the microbe by offering nutrients, physical protection, and means of reproducing and spreading. The endophyte enhances the ecological fitness of the grass, meaning that the grass is better able to compete and survive.

The endophyte resides in the plant as hyphae (Fig. 1), which are asexual strands of mycelia, in most of the plant parts. The hyphae grow between plant cells in the base of the plant and invade the leaf sheath, elongating stem, and developing seeds. The hyphae then lie dormant in mature seeds until they germinate and form a new generation of plants. The reactivated hyphae grow out of the seeds and into the seedling. The hyphae of *Neotyphodium* species cannot survive outside the plant; in fact, they have lost the ability to form spores and transmit from plant to plant.

Figure 2. Tall fescue plants in full bloom and ready to harvest for hay. (PHOTO BY H. MEDDERS)

That trait permits managers to control the presence and type of endophyte used in new grass populations.

Tall fescue (Fig. 2) was introduced to North America from Europe in the nineteenth century, as were many cool-season grass species now used as forages (Hoveland 2009). Tall fescue was widely planted in the humid zones of North America in the 1950s and 1960s, especially in the cool- to warm-temperate transition zone of the eastern U.S., and in the humid Pacific Northwest (West and Waller 2007). The endophytic fungus *N. coenophialum* is commonly found in the eastern U.S. in tall fescue populations that derived from the cultivar Kentucky 31. That cultivar was successful largely because of the benefits that its endophyte conferred to the plants. *Neotyphodium* endophytes were observed in tall fescue and ryegrasses in the 1940s; however, their agricultural importance was not elucidated until the 1970s and 1980s (Hoveland 1993).

Perennial ryegrass is another cool-season grass introduced from Europe that contained a similar endophyte, *N. lolii*. In addition to the cool, maritime areas of Europe, this grass is widely used for pasture in New Zealand, parts of Australia, and cool, humid zones of North America. It was

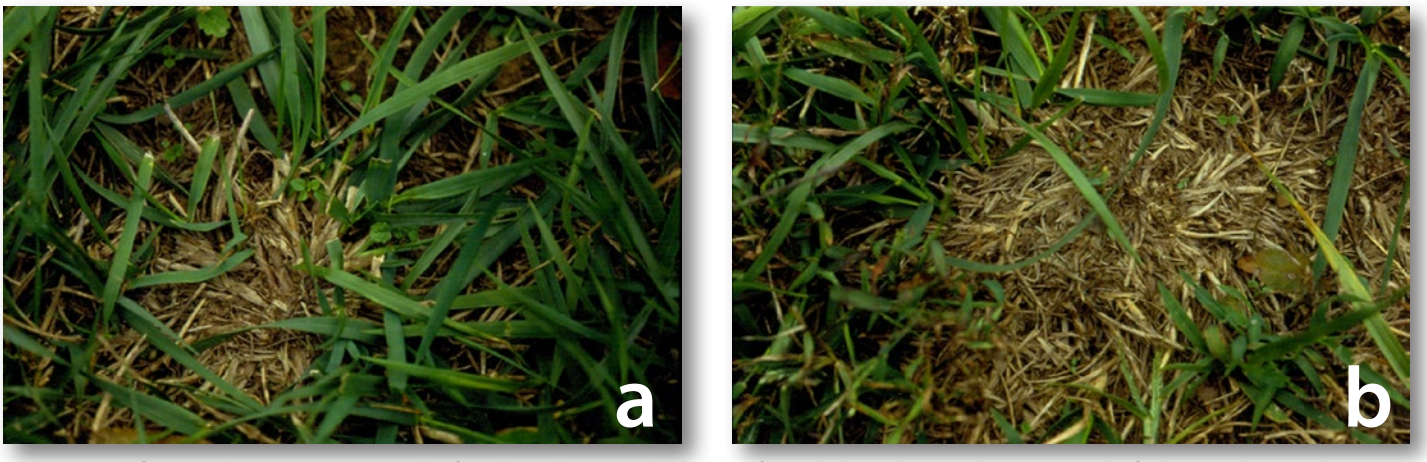

Figure 3. Tall fescue plants upon regrowth after drought. a) Endophyte-infected plant showing high survival of tillers with no crabgrass *(Digitaria sanguinalis)* ingress. b) Endophyte-free plant showing low tiller survival with crabgrass ingress along lower part of photo.
(PHOTOS BY C. WEST)

Figure 4. a) Beef steers grazing endophyte-infected tall fescue and making mud around the waterer and showing rough hair coat, while b) steers grazing endophyte-free tall fescue have smooth hair coats and spend more time grazing. (PHOTOS BY C. WEST)

in New Zealand in the early 1980s that this endophyte was rediscovered in perennial ryegrass, and other *Neotyphodium* species were subsequently found in related ryegrass species (Fletcher 2005).

Endophyte benefits to plants

Part of the mutualism is that plants benefit from their endophytes. In tall fescue, the endophyte increases the plant's ability to compete against neighboring plants, reproduce by tiller growth and seed production, survive drought, and resist or deter certain diseases and herbivores (West 1994) (Fig. 3). Herbivores include nematodes, or microscopic worms that feed on roots, and insects that consume various plant parts including stems and leaves. Deterrence of nematode feeding by the presence of endophyte directly benefits the host by preventing the diversion of energy from plant to parasite, therefore protecting plant vigor (Timper 2009). Endophyte deterrence of nematode feeding also allows roots to exploit soil water reserves, thereby indirectly forestalling the negative impacts of drought (Elmi et al. 2000). The chemical agent responsible for nematode deterrence in endophyte-infected tall fescue plants has not been identified.

The *N. lolii* endophyte in perennial ryegrass pastures in New Zealand protects the grass from devastating damage to stems and growing points by the Argentine stem weevil (*Listronotus bonariensis*) (Prestige and Gallagher 1988). The endophyte produces the alkaloid peramine, the chemical agent responsible for weevil deterrence (Rowan and Gaynor 1986). Other strains of *N. lolii* deter other insects, such as the root aphid (*Aploneura lentisci*) (Popay 2009). In this case, there is a clear benefit of the endophyte in an environment where the weevil is common. In tall fescue, controlled studies have shown deterrence of feeding by bird cherry-oat aphid (*Rhopalosiphum padi*) when infected with endophyte. This insect can vector barley yellow dwarf virus (Mahmood et al. 1993), which can reduce plant growth. This demonstrates an indirect benefit of the endophyte on conferring resistance to a disease. Despite numerous examples of *Neotyphodium* endophytes inhibiting or deterring insects in controlled studies, no widespread benefits for insect resistance in tall fescue have been found in the field (Popay, 2009).

Endophyte effects on animals

Herbivores also include large animals such as wildlife and agricultural livestock. Deterrence of feeding by such animals helps the plant survive and reproduce; however, it is a serious economic problem when livestock are negatively affected. Hoveland (1993) estimated $600 million annual losses in the U.S. due to endophyte-induced disorders in beef cattle alone, based on lost income from reduced calf weaning weights, slow growth of stockers and replacement animals, and low cow conception rates. Reduced bull performance adds to the general decline in herd productivity. Losses are even greater when including dairy cows and high-value horses.

Fescue toxicosis is a suite of endophyte-induced disorders in animals grazing or fed tall fescue (Hoveland 2009). Summer syndrome in cattle is a general term referring to poor weight gain and/or milk production resulting from low forage intake and heat stress. Symptoms include elevated body temperature, retention of winter hair coat, and high respiration rate. Cattle often stand in water and mud for relief (Fig. 4). Fescue foot refers to necrosis of tissues at the extremities, such as hooves, ears and tails, where poor blood flow due to vasoconstriction fails to maintain healthy tissues (Fig. 5). Gangrene can develop, leading to advanced necrosis and loss of the extremities. Fescue foot occurs more frequently in cold months because low temperatures aggravate the effects of poor blood circulation on animal tissue necrosis.

The endophyte in perennial ryegrass can also induce symptoms in cattle and sheep related to vasoconstriction. Ergopeptine alkaloids and their ergot alkaloid metabolites inhibit the animal's ability to dissipate body heat because of vasoconstriction and thus reduced blood flow (Strickland et al. 2009). Such alkaloids are produced in both tall fescue

and perennial ryegrass. A common alkaloid of this group is ergovaline, which is often measured as an indicator of potential toxicity. In New Zealand, the most prevalent disorder in sheep related to endophyte infection is ryegrass staggers, a syndrome manifested by unsteady gait in mild cases to complete collapse and loss of mobility in advanced cases, and sometimes death. The alkaloids responsible for ryegrass staggers are neurotoxins, lolitrem B and their derivatives. These alkaloids are not produced in tall fescue.

Management options and the win-win solution

Discoveries of the role of endophytes in causing disorders in livestock consuming tall fescue and perennial ryegrass led to replacing infected stands with new plantings lacking the endophytes, with dramatic improvements in animal performance and health. Many of those stands, however, especially in the southeastern U.S., showed rapid thinning associated with drought and likely

Figure 5. Beef heifer exhibiting loss of tail switch resulting from cool-season grazing of endophyte-infected tall fescue.

(PHOTO FROM UNIV. OF MISSOURI EXTENSION SERVICE)

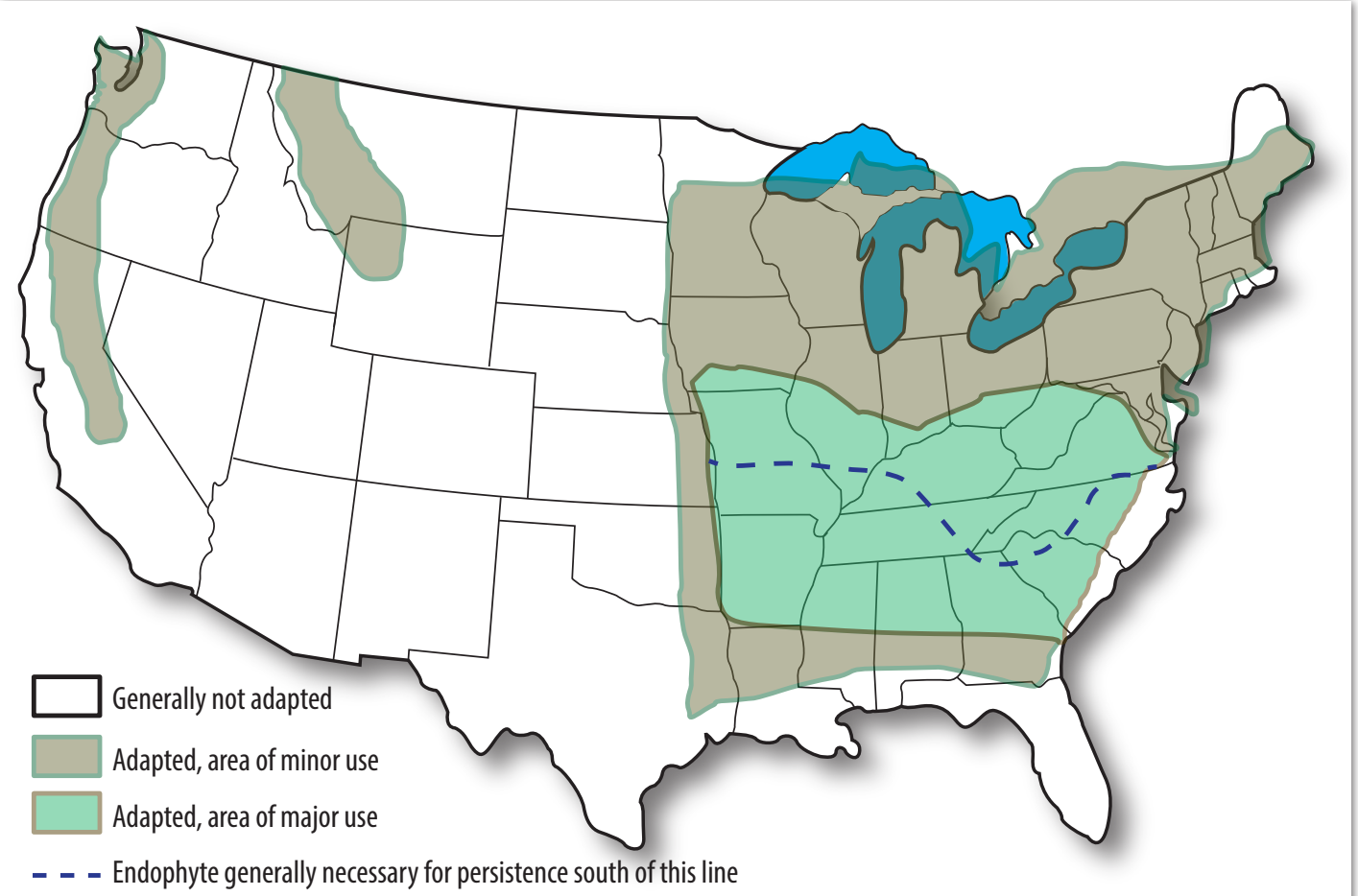

Figure 6. Map of the U.S. and portions of southern Canada showing zones of adaptation and use of tall fescue. Tall fescue is adapted to most of the northern U.S. and southern Ontario; however, other cool-season grasses may be more widely used. The major-use zone is in the east-central and southeastern U.S., often referred to as the transition zone. The dashed line indicates a gradual boundary, south of which the endophyte *N. coenophialum* is preferred to reduce the risk of stand loss due to water deficit and heat.

(ADAPTED FROM WEST, 1999)

overgrazing. Realization of the myriad benefits to stand persistence afforded by the endophytes presented a dilemma to livestock producers: eradicate the grass with the toxic endophyte and replace with an endophyte-free planting, thereby improving livestock production in the short term but with the risk of stand loss, or manage the existing stand of grass with the confidence that stands will persist, but with livestock performance that is below potential.

Several approaches to minimizing these problems in tall fescue are practiced today.

1. Replace at least some of the toxic tall fescue stand with other forages which fill a seasonal production gap, such as warm-season species for summer production, and retain the existing tall fescue while managing for reduced toxicosis severity (Roberts et al., 2009). Utilizing warm-season species during summer relieves livestock of the aggravation of heat stress caused by ergot alkaloids. The remaining endophyte-infested tall fescue could receive interseedings of legumes such as white clover (*Trifolium repens*) to dilute the intake of toxins, enhance the nutritive value of the ingested forage, and provide a low-cost source of nitrogen input. Reducing or eliminating fertilization with nitrogen reduces the synthesis of ergot alkaloids by the endophytes. Supplementing the grazing with a by-product feed high in digestible fiber, such as soy hulls, would also reduce toxin intake by cattle on infested pastures (Andrae and Roberts 2007).
2. Replace the toxic tall fescue with an improved endophyte-free cultivar in a zone that is not characterized by consistently high summer temperatures and water deficit, and on soils with good water holding capacity. In the eastern fescue belt of the U.S., that would be north of the dashed line in Fig. 6. These areas are north of the Ozark Highlands in Missouri and extend to the higher elevations of the Appalachians. Select sites whose soils allow good water infiltration and deep rooting. Take care to prevent grazing the grass short, especially during periods of water deficit.
3. Replace the toxic tall fescue with a cultivar containing a novel endophyte strain, that is, one selected for inability to synthesize ergot alkaloids, but retaining benefits for plant persistence. This technology was pioneered by researchers at AgResearch of New Zealand when they selected strains of *N. lolii* lacking lolitrem B causing ryegrass staggers, but retained peramine, which deterred Argentine stem weevil (Fletcher 2005). In the case of tall fescue, strains of *N. coenophialum* have been identified which promote plant drought survival while averting fescue toxicosis (Bouton and Easton 2005) (Fig. 7). Cultivars containing novel endophyte strains are now commercially available. They are recommended where endophyte-free cultivars are at risk of stand reduction due to water deficit, heat, nematodes, and overgrazing, especially those areas south of the dashed line in Fig. 6. In fact, many pastures north of that line would be candidates for establishment of novel-endophyte fescues to hedge against changes in climate resulting in wide swings in precipitation and rising temperatures.

Figure 7. Inoculation of tall fescue seedlings with a strain of endophyte which lacks ergot alkaloids. The seedlings are grown up in a greenhouse until ready for transplanting to a seed-production block in the field. Those plants will produce seeds that contain the new, beneficial endophyte for eventual pasture establishment. (PHOTO BY C. WEST)

Endophytes in tall fescue and perennial ryegrass challenge forage managers to respect and understand the natural complexity of grasses, microbes, herbivores, soil, and climatic environment when designing best practices for providing year-round, high quality forage at lowest cost. Novel-endophyte technology offers tools for producers to attain a high level of sustainable livestock productivity and health on pastures in the face of increasing climatic risk and input costs.

References available online at www.farmwest.com

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