Accepted for publication 24 May 2006. Published 12 September 2006.

Birdsfoot Trefoil, a Valuable Tannin-Containing Legume for Mixed Pastures

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MacAdam, J. W, Griggs, T. C., Beuselinck, P. R., and Grabber, J. H. 2006. Birdsfoot trefoil, a valuable tannin-containing legume for mixed pastures. Online. Forage and Grazinglands doi:10.1094/FG-2006-0912-01-RV.

Introduction

Legumes are important components of pastures. Legumes not only fix atmospheric nitrogen (N_2) for their own use when properly inoculated, they provide nitrogen (N) for associated grasses and forbs. A range from 150 to 240 lb N per acre is needed to equal the contribution of legume N in legume-grass mixtures (14). Using a legume reduces the purchase and application costs of N fertilizer and may reduce soil acidification and N losses to the environment. Many legumes are deep-rooted and therefore more drought-tolerant than grasses. Under grazing, legumes are more commonly used as a component of mixtures with grasses than as monocultures. This is because fibrous-rooted grasses are valuable sources of soil organic matter, they provide better protection from soil erosion, are more resistant to grazing and treading damage than legumes, and well-managed grass-legume mixtures provide more-than-adequate levels of crude protein (CP) for highly productive livestock.

Legumes have higher nutritive value and voluntary intake than grasses (18), and steer gains are higher on legume-grass mixtures than on N-fertilized grass monocultures (14). However, most legumes can cause bloat. In a uniform stand, a maximum of 50% bloat-causing legume is considered bloat-safe, but bloat has been reported in mixtures with less than 15% bloat-causing legume where selective grazing could occur (30). The low digestibility of tropical legumes has been attributed to their high tannin content (53). Well-managed temperate grass-legume pastures, however, can have excessive CP and therefore animal performance can benefit from the presence of moderate concentrations of condensed tannins that control bloat and decrease ammonia and methane production in the rumen while increasing rumen undegradable protein (58).

There are several species in the genus *Lotus* that produce condensed tannins in high enough concentrations to influence herbage digestibility and animal performance. Big trefoil (*Lotus uliginosus* Schkur.) produces concentrations of tannins at levels high enough to be considered an antiquality component (2). In contrast, birdsfoot trefoil (*L. corniculatus* L.; BFT) has lower herbage tannin concentration, but levels can be high enough to be beneficial. This review will discuss agronomic aspects of BFT and assess studies that have compared the livestock production value of BFT with forages that contain little or no condensed tannin. Many studies of tannins in BFT have been carried out in New Zealand with sheep, but studies with cattle are included where available.

Adaptation and Establishment of Birdsfoot Trefoil

The geographic range of BFT. *Lotus* species are found throughout the world, but the greatest species diversity occurs in regions with Mediterranean climates: the Mediterranean basin, the far western USA, and northwestern Mexico (36). Birdsfoot trefoil is one of the most widely distributed *Lotus* species and the most widely used (12). It is the major pasture species in Argentina and Uruguay, and is cultivated throughout North and South America, Europe, the British Isles, South Africa, New Zealand, Australia, Japan, and South Korea (12), and it has a number of colorful and otherwise descriptive local names, i.e., trefoil, common bird's-foot trefoil, birdfoot deervetch, birdsfoot clover, baby's slippers, and bacon and eggs. In North America, alfalfa (*Medicago sativa* L.) is grown in preference to BFT on deep fertile soils, while BFT has proven to be better adapted on soils too acidic or limited in fertility, texture or rooting depth for successful alfalfa production (17,29,34,63). Some BFT cultivars are also more saline-tolerant than alfalfa and white clover (*Trifolium repens* L.) (33,41,61).

Establishment and persistence. Birdsfoot trefoil is reputed to be difficult to establish (12,25,63,66) and to have poor competitiveness and persistence (1,3,11) in spite of its self-reseeding characteristic. English (23) reported that Fusarium wilt caused stand decline in the northeastern USA, and crown and root diseases limited the persistence of BFT in the eastern and central USA. These and other diseases are more prevalent in warm, humid climates, also limiting the use of BFT in the southern USA. Figure 1 illustrates the variation in establishment and growth of a number of cultivars of BFT and alfalfa under irrigation in the Intermountain West, where both species are well-adapted.

A **B**

Fig. 1. Comparative establishment and initial growth in July following an April seeding (**A**) and mature stands one year later (**B**) of irrigated birdsfoot trefoil (yellow flowers) and alfalfa cultivars (violet flowers) at Logan, Utah.

Birdsfoot trefoil is a long-day plant requiring at least 14 h of daylight to flower and set seed. Because individual plants may survive for only two to three years, BFT has been most successfully grown at latitudes greater than 30° where natural reseeding is possible (12). Grazing management is also a factor in stand persistence of BFT. In an Ohio study, stands of BFT grown with Kentucky bluegrass (*Poa pratensis* L.) decreased 90% under continuous stocking and only 20% under rotational stocking (70). In comparison with alfalfa, BFT can be defoliated more frequently, but because it does not store carbohydrates during the growing season as does alfalfa, photosynthesizing tissues must be left to support the next regrowth cycle (55,67). Management-intensive grazing of BFT-grass mixtures is practiced for successful long-term persistence and productivity of BFT (46,64). Wen et al. (76) reported BFT in the diet selected by heifers grazing BFT-tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh.] to be greater than the proportion of BFT on offer, indicating that grazing management should consider livestock preferences for BFT (Fig. 2).

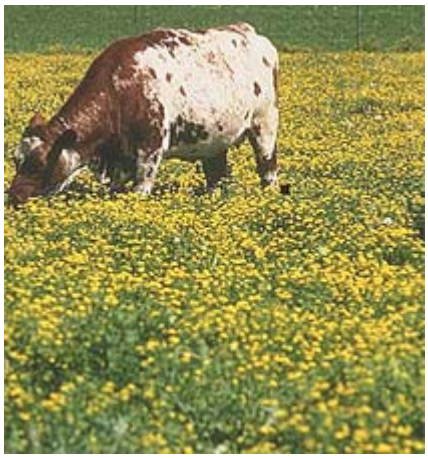

Fig. 2. Birdsfoot trefoil is a high-quality legume that can be grazed without bloat problems, and with additional benefits of increased rumen undegradable protein.

Rooting attributes. Birdsfoot trefoil is predominantly tap-rooted, but rhizomatous germplasms have been selected and released (6,9,10). The root system of BFT is more shallow and branched than alfalfa but with greater lateral spread (25,63,66); it is therefore more flooding- and heaving-tolerant but less drought-tolerant than alfalfa (56). Birdsfoot trefoil performs better on low-phosphate soils than alfalfa (12), which could also be related to differences in root system morphology.

Rhizobia. Like other forage legumes, BFT will fix N_2 in symbiosis with the proper bacterium. Nodulation in BFT occurs in association with *Rhizobium loti* (71), while alfalfa is inoculated with *Sinorhizobium meliloti*. Since these inocula are different species, a residual presence of alfalfa inoculum in the soil is of no value to BFT. It should be noted that the nomenclature for the bacterial symbiont varies, with some authors referring to it as *Bradyrhizobium loti*. Jarvis et al. (32) have proposed moving a group of rhizobia including *Rhizobium loti* to a new genus *Mesorhizobium*.

Inoculation. Depending on the source, BFT seed may be sold with the proper inoculum already applied, or fresh inoculum may be purchased separately and applied to uninoculated seed. It is critical that fresh inoculum or properly inoculated seed be used in order for nodulation, and therefore N_2 fixation, to be effective. The group of rhizobia to which the inoculum for BFT belongs is well-adapted to neutral or alkaline soils (12) so if BFT is to be seeded into acidic (pH < 5.5) soils, inoculated seed should also be pelleted with lime to aid in survival of the inoculum. Since BFT nodules senesce when herbage is removed, regrowth of grazed BFT should benefit from low levels of manure or fertilizer N while new nodules are developing.

Seeding. Recommended seeding rates vary from as little as 1 lb/acre in complex mixtures to 10 lb/acre in monoculture (12). Seed of BFT are small compared to some other legumes (half the weight of alfalfa seed), making calibration of seeding equipment somewhat challenging. Birdsfoot trefoil seedlings are less vigorous than alfalfa (Fig. 1) and less competitive with grass or weed species (63). Therefore, overseeding an established stand of grass with BFT is not recommended unless the grass is chemically or mechanically suppressed (12), but successful frost seeding into established switchgrass (*Panicum virgatum* L.) stands has been reported (26). Certified seed should be used to ensure that seed is of the named variety and free of prohibited weed seeds. The pure live seed percentage reported on the seed tag, excluding hard seed, should be used to calibrate planters.

Benefits of Condensed Tannins in Birdsfoot Trefoil

Condensed tannins are natural phenolic polymers found in some forage legumes that cause protein to precipitate or come out of solution. BFT contains soluble and insoluble tannins (69) and while both interact with proteins, only the former are routinely measured with some accuracy (62). Tannin levels in BFT tend to be low (~0.5% DM) in germplasm originating from North America and Asia Minor, intermediate (~2.5% DM) for northern European germplasm, and high (>4% DM) in germplasm originating from the Mediterranean region (68). Tannin levels are influenced by growth conditions but they tend to increase with plant maturation, are highest in midsummer, and are higher in leaves than stems (15,16,48).

Bloat. Legume bloat can begin as quickly as 15 min after cattle are turned onto a bloat-causing pasture, and death can occur 2 to 4 h after the onset of bloat (30). All true clovers (*Trifolium* spp.) and alfalfa can cause bloat. Bloat occurs when a stable froth composed of soluble plant proteins and cellular organelle particles from leaf mesophyll (the interior photosynthetic cells of leaves) combine in the rumen with slime from bacteria that are rapidly proliferating due to the availability of high concentrations of plant cellular carbohydrates during digestion (30). Bloat is prevented in the case of BFT and a few other forage legumes [e.g., sainfoin (*Onobrychis viciifolia* Scop.), serecia lespedeza (*Lespedeza cuneata* [Dum.-Cours.] G. Don), annual lespedezas (*Lespedeza stipulacea* Maxim. and *Kummerowia striata* [Thunb.] Schindl.). and sulla (*Hedysarum coronarium* L.)] by condensed tannins, even at very low concentrations (<0.5% DM). Tannins bind with proteins released from the mesophyll cells of chewed forage and reduce the activity and numbers of rumen bacterial that thrive on protein (49,50). Condensed tannin-protein complexes reduce the soluble protein content of the rumen and help prevent formation of the stable froth that leads to bloat (35). A thick cuticle and thick mesophyll cell walls enhance bloat prevention in BFT and some other non-bloating legumes by slowing the release of cell contents during mastication and fiber digestion by rumen microbes (30,39).

Protein utilization. The stable condensed tannin-protein complexes that form under the mildly acidic conditions in the rumen (pH 5.5 to 7.0) can improve the efficiency of ruminant protein utilization by reducing microbial degradation of forage protein to ammonia. Most tannin-protein complexes dissociate under the acidic conditions of the abomasum (pH 2.5 to 3.5), allowing proteins to become soluble again, and therefore permitting greater amino acid absorption in the small intestine compared to tannin-free forages (3). Due to greater utilization of forage protein, ewes and lambs grazing tannin-containing BFT in place of alfalfa or white clover-perennial ryegrass (*Lolium perenne*) pasture usually have better wool production and quality, liveweight gain, carcass weights, body condition score, reproductive efficiency and lower mortality (22,40,60). Milk production was 12.5 lb per day greater for non-supplemented mid-lactation Holstein cows fed BFT pasture with 2.5% condensed tannin in place of an essentially tannin-free perennial ryegrass-white clover pasture (78). Milk yield was up to 11 lb/day greater with BFT silage than with alfalfa silage when fed as 50% of a total mixed ration to mid-lactation Holsteins (31). In both studies, about one-half of the milk response to BFT could be attributed to condensed tannin effects on protein utilization. Although excessive levels of condensed tannin can reduce forage legume palatability, nutrient utilization and animal production (4), most North American BFT varieties have less than 2.5% condensed tannin (68) while 3 to 4% condensed tannin is needed to improve animal production by increasing essential amino acid absorption (4,58). Therefore, in 2005, a multi-state study was initiated to identify European- and Mediterranean-derived BFT varieties with acceptable tannin levels and agronomic performance for livestock producers in the United States (J. H. Grabber, *personal communication*).

Parasite load. In addition to preventing bloat, condensed tannins in BFT reduce internal parasite levels in sheep. In one study comparing monocultures of BFT with moderate tannin (~2.5% DM) to white clover-perennial ryegrass mixtures with low tannin (0.15% DM), fecal nematode egg counts in ewes were usually lower on BFT pastures (59). Fecal egg counts in lambs grazing BFT were

initially one-third the level of lambs grazing grass-clover pasture, but increased to an equivalent level later in the experiment. Due to reduced internal parasite load and higher protein utilization, liveweight gain and wool production of ewes and lambs and weaning weight of lambs were all higher on BFT pasture than perennial ryegrass-white clover pastures. The effect of tannin-containing forages on the parasite load of cattle has not been thoroughly studied, but should be investigated, especially for low input sustainable and organic livestock production systems where synthetic treatments for parasites are avoided.

Livestock reproduction. In review articles (50,72) that compared BFT to forages with and without tannins, moderate condensed tannin concentrations (2.0 to 4.5% of forage DM) in BFT and sulla increased the ovulation rate of ewes and the efficiency of milk production in cows, most likely due to increased flow of essential amino acids to the small intestine and their subsequent absorption (5). Higher concentrations (> 5.5%) of condensed tannins, however, reduced intake and digestibility and depressed growth and wool production (4). One might assume that concentrations of condensed tannins from BFT should be a function of BFT proportion in the mixture, but this relationship may not be entirely predictable, since Wen et al. (75) showed tannin levels for BFT in mixtures with tall fescue were twice that of the same BFT in monoculture.

Polyethylene glycol (PEG) selectively binds with condensed tannins and prevents them from complexing with proteins in the rumen. In a series of studies, monoculture BFT containing approximately 2% condensed tannins per unit DM was compared with the same BFT plus PEG, and with perennial ryegrass-white clover pastures containing only trace amounts of tannins. The tannin-containing BFT resulted in higher ovulation rates and a higher number of twins than the other treatments (52); wool length and clean wool percentage were also higher.

Livestock production. Ewes fed BFT with or without PEG had the same level of intake, but ewes fed BFT with active condensed tannins had reduced rumen ammonia, and more efficient and higher quality wool production (51). Lambs fed BFT with and without PEG had higher liveweight gain with active condensed tannins (74). In a study of ewes rearing twins and fed BFT with or without added PEG, milk yield and composition were similar for the two treatments at peak lactation. However, milk production and protein and lactose secretion of PEG-supplemented ewes (i.e., without tannins) declined more rapidly than for ewes fed BFT with active tannins (73), resulting in higher milk production efficiency due to the condensed tannins in BFT. Similarly, a comparison of dairy cattle performance on white clover-, BFT-, and perennial ryegrass-dominant pastures also showed higher milk production and feed conversion efficiency for BFT than for the other forage species (28). In the US, Marten (45) demonstrated higher gains for heifers grazing tannin-containing legumes (BFT, 1.9 lb/day and sainfoin, 1.8 lb/day) than those grazing alfalfa (1.4 lb/day).

Environmental quality. Changes in N cycling and excretion induced by condensed tannins contribute to soil and water quality through reduced total and urinary losses of N (72). Due to improved protein use and reduced urea excretion, feeding BFT in place of alfalfa in total mixed rations reduced ammonia emissions from manure by 25 to 45% (54). Methane is a greenhouse gas that accounts for about 20% of global warming, and generation of methane by rumen microbes and emission from ruminants is reduced by the presence of condensed tannins (79). In a study comparing silage from perennial ryegrass pasture with silage made from BFT, cows produced one-quarter of the methane per unit DM intake on BFT, compared to perennial ryegrass (79). However, DM intake was 38% higher and milk production was 26% higher on BFT, so methane production per cow was statistically the same. In a study where sheep grazed perennial ryegrass or BFT pastures, methane emission per unit neutral detergent fiber intake was one-third less on BFT (57). The same study demonstrated that the condensed tannins from BFT were more effective in decreasing methane than the condensed tannins from the legume sulla.

Agronomic Performance of Birdsfoot Trefoil Mixtures

Birdsfoot trefoil is adapted across a wide range of temperate environments and has a moderate concentration of condensed tannins that prevent bloat and improve livestock production without acting as an antiquality factor. However, considering the challenges noted earlier with establishment and persistence, how productive is BFT compared with other legumes used in mixtures?

Grazing monocultures of BFT is rarely practiced and has generally been limited to stands grown for seed production (P.R. Beuselinck, *personal communication*). Otherwise, BFT is grown as a component of grass-dominated pastures. Root and crown diseases that reduce BFT plant longevity and stand persistence have previously been described. Self-reseeding alleviates that problem somewhat, but high BFT plant mortality in monocultures would create an environment conducive to invasion of BFT by weeds (grasses and herbaceous dicots) that benefit from the available N and open ground. Bunchgrass monocultures have interplant spaces that can be filled with weed or legume species. It is logical to fill those interplant niches with N-fixing legumes that can contribute to herbage yield and quality, and in the case of BFT, not cause bloat.

Grass-legume mixtures often yield more than N-fertilized grass monocultures (8,20,24). For example, in Iowa, mixtures of alfalfa with smooth brome (*Bromus inermis* Leyss.), orchardgrass (*Dactylis glomerata* L.), and intermediate wheatgrass [*Thinopyrum intermedium* (Host.) Barkw. & D.R. Dewey] were three times more productive than these grasses in monoculture fertilized with 60 lb N per acre, while yields of mixtures were double that of grass monocultures when the legume was BFT or kura clover (*Trifolium ambiguum* Bieb.) (65).

In a Michigan study of rotationally stocked grass-BFT mixtures, productivity of the BFT component when averaged across all harvests at two locations for two years ranged from 0.8 tons/acre per year in perennial ryegrass mixtures to 2.0 tons/acre per year in tall fescue mixtures (38). Composition ranged from about 20% BFT with tall fescue and orchardgrass to 39% with timothy (*Phleum pratense* L.). In established pastures comprised of smooth brome, quackgrass [*Elytrigia repens* (L.) Nevski.] and Kentucky bluegrass in a Minnesota grazing study (21), sod was suppressed with an herbicide and legumes were interseeded. Alfalfa and BFT comprised 53 and 48% of mixtures averaged over the four years after planting, while kura clover comprised 90%. A level of 35% bloat-causing legume is often recommended for grazed pastures (19).

An eight-year-long furrow-irrigated clipping study conducted in New Mexico compared a tall fescue monoculture fertilized with 120 lb N per acre per year with fescue-legume mixtures (27,37). During the first four years of the study, the tall fescue monoculture yielded an average of 2.8 tons/acre per year, while yields of mixtures with alfalfa, BFT, kura clover, and cicer milkvetch (*Astragalus cicer* L.) averaged 5.4, 3.9, 3.6 and 2.5 tons/acre per year, respectively. Legumes comprised 76, 53, 66, and 33% of total DM production. In the fifth to eighth years, yields were 3.5 tons/acre per year for fertilized tall fescue monocultures, and yields of mixtures were 5.7, 3.6, 6.3 and 2.3 tons/acre per year for alfalfa, BFT, kura clover, and cicer milkvetch mixtures, respectively, in which legumes comprised 56, 37, 72, and 14% of total DM production. Mean forage yields of the first and second four-year terms of the study were similar, indicating persistence of all forage species.

One agronomic trait that appears to be advantageous to the performance of legumes is rhizomatous growth, such as is found with kura clover. Rhizomatous BFT germplasm (Fig. 3) has been developed and tested (9,10). The performance of 'Norcen' BFT, a broadleaved type with intermediate growth habit developed for the North Central USA (47) and a rhizomatous BFT (ARS2620) was compared at a number of sites in the USA (Madison WI, Ithaca NY, Ames IA, Logan UT, and Columbia MO) (7). While Norcen performed best in Madison, the rhizomatous BFT produced much larger and heavier crowns and rhizomes in Logan. Herbage of the rhizomatous BFT germplasm and 'Grasslands Creeping,' a prostrate spreading type of BFT from AgResearch New Zealand, also has higher concentrations of condensed tannins than are found in Norcen and many other BFT cultivars (75,77).

Fig. 3. New developments in breeding birdsfoot trefoil have produced germplasms that can produce rhizomes. Rhizomes can allow plants to spread vegetatively and may lead to improved persistence.

In a three-year-long simulated grazing study carried out in Logan, UT, BFT mixtures out-yielded alfalfa in mixtures with meadow brome, perennial ryegrass and tall fescue, but not in mixtures of alfalfa with Kentucky bluegrass or orchardgrass (42). In the same study, white clover-grass mixtures averaged 17% more DM production than alfalfa- or BFT-grass mixtures. Figure 4 illustrates the well-integrated grass and legume components of BFT- and white clover-grass mixtures in this study. In a three-year-long grazing study in Logan, UT (Fig. 5), yields of BFT-grass mixtures exceeded the yields of white clover-grass mixtures by 8% (43), while legume proportion of BFT mixtures (29%) was more than double that of white clover in mixtures (44). In a study carried out on a calcareous (pH 7.9) soil in the UK, BFT cultivars yielded more in both monoculture and mixtures than white clover (13).

Fig. 4. Grass-legume mixtures in an irrigated clipping study near Logan, Utah. Left to right: white clover-tall fescue, birdsfoot trefoil-perennial ryegrass, and birdsfoot trefoil-orchardgrass.

Fig. 5. Rotationally stocked paddock in an irrigated grazing study near Logan, Utah.

Summary

- Birdsfoot trefoil is well-suited for use in grazed pastures, and appears to perform especially well on calcareous soils.
- The level of condensed tannins in BFT has been shown to increase rumen undegradable protein, improving productivity and reproductive health while reducing methane and ammonia emissions in sheep and cattle.

- In combination with leaf and cell anatomy, tannins in BFT prevent bloat but are at concentrations that do not constitute an antiquality factor.
- Birdsfoot trefoil grows well with pasture grasses, producing a physically integrated mixture that promotes efficient intake.
- Once established, BFT performs well and persists under grazing in mixtures with pasture grasses compared with other legumes.
- Grazing management is a key factor to long-term persistence and productivity of this self-reseeding legume in pastures.

Acknowledgment

Support for studies related to this publication was provided by the Utah Agricultural Experiment Station, Utah State University, Logan, Utah. Approved as journal paper no. 7778.

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