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RESEARCH

Perspective on Forage Legume Systems for the Tallgrass and Mixed-Grass Prairies of the Southern Great Plains of Texas and Oklahoma

T. J. Butler* and J. P Muir

ABSTRACT

Legumes have potential to transfer fixed N to nonlegume crops via grazing or decomposition as well as improve production, seasonal distribution, nutritive value, soil structure, and fertility in forage systems. This article summarizes the legume establishment, management, and grazing production experiments conducted in the southern Great Plains. It attempts to give perspective on the current state of producer adoption and the potential for future research to improve legume adoption. Several medics (*Medicago* spp.) and clovers (*Trifolium* spp.) are compatible and can be established with tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort]; however, due to limited precipitation, these have not reliably regenerated. Hairy vetch (*Vicia villosa* Roth) required annual establishment and was not as economical as N fertilizer in the perennial grass systems, but it was profitable and comparable to the annual system with 112 kg N ha^{-1} by conventional fertilizer. Alfalfa (*Medicago sativa* L.) may have the greatest potential in the southern Great Plains with cool-season perennial grass systems like tall fescue when planted in a checkerboard orientation. An alternative approach for utilizing legumes may be to limit grazing access in pure stands similar to a supplementation program during periods of limited forage production or quality. There is a need for greater research including germplasm and rhizobia evaluations, improved seed production, weed control, and grazing before producer adoption becomes widespread. Future research should address constraints including legume establishment, management practices that extend the life of legumes in forage systems, and appropriate economic analysis of proposed novel systems.

T.J. Butler, The Samuel Roberts Noble Foundation, 2510 Sam Noble Pkwy., Ardmore, OK 73401; J.P. Muir, Texas AgriLife Research, 1229 N. Hwy. 281, Stephenville, TX 76401. Received 21 Dec. 2011. *Corresponding author (tjbutler@noble.org).

LEGUME OVERVIEW

Legumes have potential to fix N that may be made available to nonlegume crops and improve forage production, seasonal distribution, nutritive value, and soil structure and fertility in forage systems (Howieson et al., 2000). Legumes are inherently appealing to those seeking agricultural systems that are independent of constant fertilizer inputs (Pearson, 2007). In warm climates, however, legumes have not been widely adopted by farmers and ranchers (Thomas and Sumberg, 1995). In drier climates subject to temperature extremes, adoption of legumes in forage systems is particularly difficult (Muir et al., 2011). In order for legumes to be successful in forage systems, several criteria must be met. First, legumes must be well-adapted to the environment. Second, they must establish easily, be compatible with grasses, and be grazing tolerant. Finally, they must be economically superior to the standard system. This article summarizes legume germplasm evaluation, establishment, management, and grazing production–economic experiments conducted in the tallgrass and mixed-grass prairies of the southern Great Plains of Texas and Oklahoma. This review also attempts to identify successful and unsuccessful legumes and production systems and give a perspective on current state of the research and producer adoption and direction for improvement of overall legume adoption by future research.

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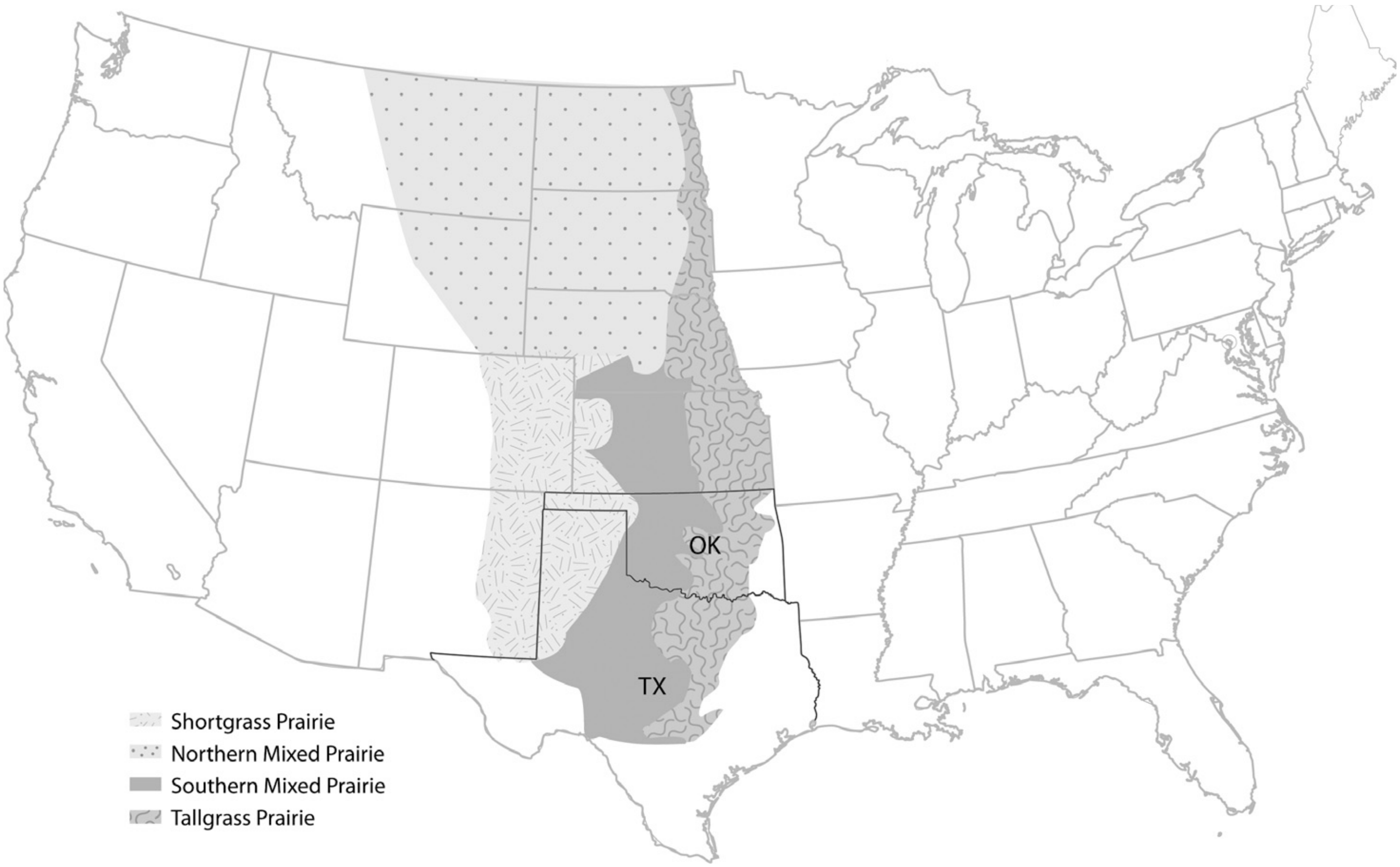

Figure 1. Grassland prairies (Great Plains) of the United States adapted from Lauenroth et al. (1994).

Description of the Southern Great Plains

In the tallgrass and mixed-grass prairies of the southern Great Plains of Texas and Oklahoma (Fig. 1), temperatures often reach −15°C during December and January and exceed 42°C during July and August. Precipitation varies widely (in an east–west gradient) across the southern Great Plains, with a range of 380 to 1020 mm annual rainfall (Fig. 2) and an average decrease of 1.2 mm km^{-1} from east to west (National Oceanic and Atmospheric Administration, 2011). Most of the research has occurred in regions ranging from 640 to 1020 mm because it is typically too dry to get reliable data in the extreme western areas. Precipitation follows a bimodal pattern, with the majority occurring in spring (April–May) and autumn (October–November) but very little occurring in summer and winter (Office of the State Climatologist, 2011). This results in a narrow window of opportunity for forage establishment. Soil type is also extremely variable, ranging from sandy loam to clay loam. Typically, the sandy soils are deficient in K, while most sandy loam and clay loam soils are deficient in P. Soil pH is variable and dependent on cropping or N fertilizer history. For example, many areas where anhydrous ammonia has been used for an extended time have an acidic topsoil but near neutral subsoil.

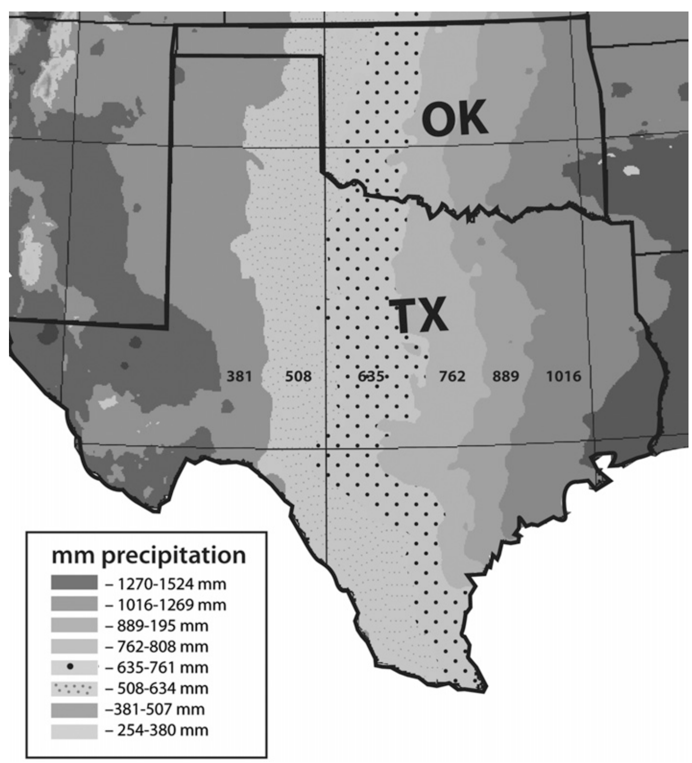

Figure 2. Precipitation (mm) map for Texas and Oklahoma adapted from http://nationalatlas.gov/climate.html.

Why Quantity and Quality Forage Is Critical to the Southern Great Plains

There is a large proportion of the national cow-calf and stocker cattle (*Bos taurus*) located in the southern Great Plains. These cattle operations are currently an important component of the economy in this region. Oklahoma and Texas, for example, contain over 75 million ha of grazing land and carry 18.4 million head of cattle (USDA-National Agricultural Statistics Service, 2011). In addition, there are sizeable populations of sheep, goats, dairy cattle, and horses. A large quantity of high-quality forage is needed for sustained productivity of these enterprises, and legumes are particularly desirable as forages due to their high nutritive value. To identify legumes that can be incorporated into grazing systems in the southern Great Plains, germplasm evaluations must be conducted.

Germplasm Evaluated

Over a period of years, several legume species have been evaluated for productivity, adaptation, and persistence for the southern Great Plains (Tables 1 and 2). These can be divided into several categories. Legumes in the southern Great Plains can grow in either summer or winter, but rarely can the same species grow during both seasons. Alfalfa is unique in that it overlaps seasons; however, it typically follows a bimodal growth distribution producing mostly in spring and autumn. Stable populations of naturalized cool-season species are almost exclusively annuals of Mediterranean origin that set seed before the summer heat (Diggs et al., 1999). Cool-season perennials such as white (*Trifolium repens* L.) or red (*T. pretense* L.) clover act as short-lived annuals and usually die out in the hot, dry summer following establishment. Alfalfa stands persist and produce well where pathogens such as cotton root rot (caused by *Phymatotrichum omnivorum*) are not prevalent (Fig. 3).

Table 1. Cool-season legumes evaluated in the southern Great Plains of the United States.

Species	Common name	No. accessions evaluated	Rhizobia strain†	Adapted	Reference‡
Lotus spp.	Trefoil				
L. corniculatus L.	Birdsfoot	10	Trefoil	No	UPD
L. pedunculatus Cav.	Big	7	USDA 3469	No	UPD
L. tenuis Waldst. and Kit. ex Willd	Narrowleaf	3	Trefoil	No	UPD
Medicago spp.	Medic				
M. arabica (L.) Huds.	Spotted burr	80	WSM 1115	No	
M. lupulina L.	Black	245	M2	No	Butler et al., 2011a
M. minima L.	Little burr	215	WSM 1115	Yes	Butler et al., 2011a
M. orbicularis (L.) Bartal	Button	337	WSM 1115	Yes	Butler et al., 2011a
M. polymorpha L.	Burr	20	WSM 1115	No	UPD
M. rigidula (L.) All.	Tifton burr	159	alfalfa	Yes	Butler et al. 2011a
M. rigiduloides E. Small	Rigid	195	M49	Yes	Butler et al. 2011a
M. sativa L.	Alfalfa	–	Alfalfa	Yes	
Melilotus spp.	Sweetclover				
M. alba Medik.	White	1	Alfalfa	No	Butler and Muir, 2004
M. officinalis (L.) Lam	Yellow	1	Alfalfa	No	Butler and Muir, 2004
Pisum sativum L. *arvense*	Field pea	50	Nitragin C	Yes	UPD
Trifolium spp.	Clover				
T. alexandrinum L.	Berseem	1	Nitragin R/WR/O	No	Butler and Muir, 2004
T. ambiguum M. Bieb.	Kura	1	USDA 2126	No	UPD
T. hirtum All.	Rose	1	WSM 1325	Yes	Butler and Muir, 2004
T. incarnatum L.	Crimson	1	Nitragin R/WR/O	Yes	Butler and Muir, 2004
T. nigrescens Viv.	Ball	1	Nitragin B	Yes	Butler and Muir, 2004
T. pratense L.	Red	1	Nitragin B	Yes	Butler and Muir, 2004
T. repens L.	White	1	Nitragin B	No	
T. subterranean L.	Sub	1	Nitragin R/WR/O	No	Butler and Muir, 2004
T. vesiculosum Savi	Arrowleaf	2	USDA 2298	Yes	Butler and Muir, 2004
Vicia spp.	Vetch				
V. angustifolia L.	Narrowleaf	1	?	No	UPD
V. grandiflora Scop.	Bigflower	1	Nitragin C	No	UPD
V. sativa L.	Common	595	Nitragin C	No	UPD
V. villosa Roth	Hairy	87	Nitragin C	Yes	UPD

†Butler et al. (2010).

‡UPD, unpublished data.

Table 2. Warm-season legumes evaluated in the southern Great Plains of the United States.

Species	Common name	No. accessions evaluated	Rhizobia strain†	Adapted	Reference‡
Acacia angustissima (Mill.) Kuntze	Prairie acacia	10	?	Yes	
Arachis glabrata Benth.	Rhizoma peanut	16	?	No	Interrante et al., 2011a
Cajanus cajan (L.) Millsp.	Pigeonpea	2	Cowpea	Yes	Rao et al., 2003
Desmanthus illinoensis (Michx.) MacMill. ex B.L. Rob. and Fernald	Illinois bundleflower	1	CB 3126	Yes	Butler et al., 2011b
Desmanthus leptolobus Torr. and A. Gray		1	CB 3126	Yes	UPD
Desmodium paniculatum (L.) DC	Tickclover		CB 756	Yes	Muir et al., 2008a
Glycine max (L.) Merr.	Soybean	250	Soybean	Yes	UPD
Glycine soja Siebold and Zucc.	Wild soybean	200	Soybean	Yes	UPD
Lablab purpureus (L.) Sweet	Lablab	3	USDA 3605	Yes	Butler et al., 2011b
Macroptilium bracteatum (Nees and Mart.) Marechal and Baudet	Burgundy bean	1	?	Yes	UPD
Kummerowia stipulacea (Maxim.) Makino	Korean lespedeza	1	Cowpea	Yes	Butler et al., 2011b
Strophostyles leiosperma (Torr. and A. Gray) Piper	Smooth-seeded wild bean	6	ST-3	Yes	Butler and Muir, 2010
Strophostyles helvula (L.) Elliott	Trailing wild bean	13	ST-3	Yes	Butler and Malinowski, 2012
Vigna unguiculata (L.) Walp.	Cowpea	1	Cowpea	Yes	Muir et al., 2008b
Vigna radiata (L.) R. Wilczek	Mungbean	1	Cowpea	Yes	Muir et al., 2008b

†Butler et al. (2010).

‡UPD, unpublished data.

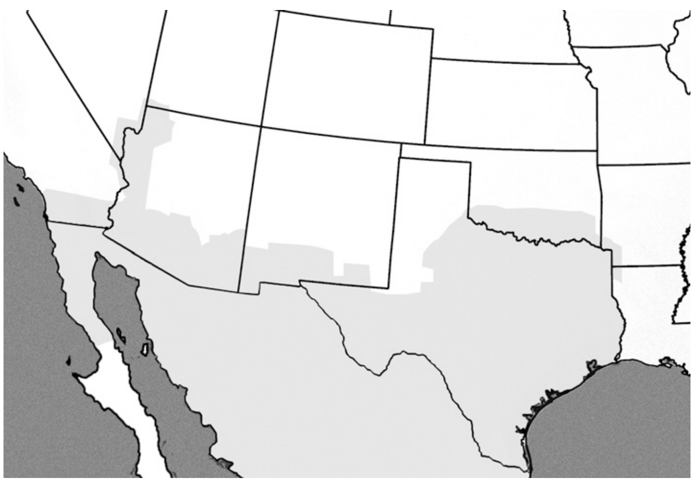

Figure 3. Distribution of *Phymatotrichopsis omnivora* (= *Phymatotrichum omnivorum*) in the southwestern United States adapted from http://www.cals.ncsu.edu/course/pp728/Phymatotrichopsis/index.html.

Cool-Season Legumes

A number of cool-season annual legumes have been evaluated at various locations in the extreme southern Great Plains, including *Vicia* spp., *Trifolium* spp., and *Medicago* spp. (Muir et al., 2005a; Muir et al., 2006). Several *Medicago* spp. cultivars with specific adaptation to the short winters of southern Texas were selected from naturalized populations in that region. These included 'Armadillo' burr medic (*M. polymorpha* L.) (Ocumpaugh et al., 2004) and 'Devine' little burr medic (*M. minima* L.) (Ocumpaugh et al., 2007). Systematic evaluation of a wider range of medic germplasm has taken place more recently at the Noble Foundation in southern Oklahoma. All available accessions (1231) from six different species—black medic (*M. lupulina* L., 245 accessions), spotted burr medic [*M. arabica* (L.) Huds., 80 accessions], Tifton burr medic [*M. rigidula* (L.) All., 159 accessions), rigid medic (*M. rigiduloides* E. Small, 195 accessions), button medic [*M. orbicularis* (L.) Bartal, 337 accessions], and little burr medic (215 accessions), were obtained from GRIN (http://www.ars-grin.gov/) or collected locally and evaluated for adaptation (freeze tolerance, winter drought tolerance, forage production, and seed production) for the southern Great Plains (Butler et al., 2011a). It was concluded that button medic followed by rigid medic had the greatest potential for the region, although rigid medics required special rhizobia inoculants (M49, an experimental strain obtained from Australia, which is now commercially available in the United States), whereas button medic was best suited with the traditional medic strain (WSM1115) but could also be effectively nodulated with the alfalfa strain (Interrante et al., 2011b). In addition, hairy vetch and field pea (*Pisum sativum* L.), with large seed size, were the only legumes to be successfully established in existing tall fescue swards (unpublished data, 2005–2007). Therefore, evaluations were expanded for common vetch (*Vicia sativa* L., 595 accessions), hairy vetch (87 accessions), and field pea (50 accessions). Based on these observations, it was determined that common vetch is susceptible to freeze damage and is not well adapted. Field pea, although well adapted for forage production, is susceptible to powdery mildew and does not produce seed consistently in this region; therefore, it cannot be used as an alternative grain crop to provide supplemental protein to livestock. Hairy vetch offers the greatest potential for interseeding in existing swards since it appears to have adequate seedling vigor and drought tolerance. However, hairy vetch has a reputation for being "weedy," especially in cereal crops produced exclusively for grain production, which may have limited its overall adoption in certain regions.

Warm-Season Legumes

Unlike the *Stylosanthes* success story in parts of Australia (Clements and Henzell, 2010), persistent populations of naturalized exotic warm-season legumes are basically nonexistent in the southern Great Plains. Tropical or subtropical annuals produce well in growing seasons with abundant and evenly distributed rainfall or under irrigation but rarely reseed themselves (Muir et al., 2008b). They are often seeded by commercial wildlife operations that are not concerned with the cost of establishment failures. Exotic tropical perennials likewise produce abundant forage the first season of planting if irrigated or if established during exceptional rainfall years (Butler et al., 2006; Rao et al., 2005). Several native legumes {trailing wild bean [*Strophostyles helvula* (L.) Elliott], smooth-seeded wild bean [*S. leiosperma* (Torr. and A. Gray) Piper], and bundleflowers (*Desmanthus* sp.)} and introduced legumes {lablab [*Lablab purpureus* (L.) Sweet], cowpea [*Vigna unguiculata* (L.) Walp.], mungbean [*V. radiata* (L.) Wilczek], burgundy bean [*Macroptilium bracteatum* (Nees and Mart.) Marechal and Baudet], Korean lespedeza [*Kummerowia stipulacea* (Maxim.) Makino], and soybeans [*Glycine max* (L.) Merr., *G. soja* Siebold. and Zucc.]} have been evaluated; however, regrowth after defoliation from grazing has been disappointing (T.J. Butler, unpublished data, 2009–2010). Rao et al. (2003) reported relatively high forage yield (6.4–12.6 Mg ha^{-1}) of pigeonpea [*Cajanus cajan* (L.) Huth.] under clipping; however, Rao and Northup (2012) later reported that cattle would only consume pigeonpea after it had flowered, which resulted in 20 grazing days stocked at 7 steers ha^{-1} resulting in 140 kg ha^{-1} total weight gain over 3-yr average. Most legumes evaluated, with the exception of rhizoma peanut (*Arachis glabrata* Benth. var. *glabrata*), do not persist beyond the first year of establishment. Several rhizoma peanut cultivars persist south of 34°N latitude (Interrante et al., 2011a), while the recently released cold-hardy 'Latitude 34' has persisted for long periods, albeit without grazing pressure, up to 30°N latitude (Muir et al., 2010).

Native legume germplasm has some potential for forage production in the southern Great Plains. In Texas alone a total of 54 native genera are documented (Turner, 1959), while in northern Texas and southern Oklahoma, for example, over 50 distinct native herbaceous legume species have been identified (Diggs et al., 1999). A few are annuals (Turner, 1959) with some forage potential (e.g., *Strophostyles* spp.) but with indeterminate flowering and dehiscing seedpods that discourage commercial application (Muir et al., 2005b; Butler and Muir, 2010). Herbaceous perennials are more common and have been more widely studied for their forage potential (Muir and Bow, 2008). These legumes were a far more important component of the grasslands and savannahs of this region before the systematic exclusion of fire (Turner, 1959). Only a few have been evaluated for their herbage or seed production potential (Muir et al., 2005b). Of those, few were released as cultivars, and even fewer, such as Illinois bundleflower [*Desmanthus illinoensis* (Michx.) MacMill. ex B.L. Rob. and Fernald], are currently commercially available (Muncrief and Heizer, 1985). Few grazing trials have evaluated these species, but the limited data uniformly show cattle preference for legumes vis-à-vis grasses (Berg, 1996) and poor persistence when interseeded with aggressive perennial grasses (Muir and Pitman, 2004). The end result is that most research with herbaceous legumes native to the southern Great Plains today focuses on reseeding rangeland or diversifying prairies where bunchgrasses predominate and stocking rates are lighter compared to cultivated pastures.

Establishment and Compatibility with Grasses

Annual medics (button, little burr, rigid, and Tifton burr) and clovers (arrowleaf [*T. vesiculosum* Savi], crimson [*T. incarnatum* L.], and rose [*T. hirsutum* All.]) have successfully been established along with tall fescue and complemented the tall fescue system. Hairy vetch and field pea, however, were too competitive with tall fescue seedlings and could not be reliable companion crops. Butler and Malinowski (2012) reported on a study comparing five summer legumes and eight winter legumes that were established at Vernon, TX (34°09′ N, 99°20′ W; Wichita clay loam [fine, mixed, superactive, thermic Typic Paleustalf]) and at Vashti, TX (33°34′ N, 98°1′ W; Anocon loam [fine, mixed, active, thermic Udic Argiustoll]) with summer-dormant tall fescue to determine the compatibility of legumes with summer-dormant tall fescue. Summer legumes (Illinois bundleflower, Korean lespedeza, smooth-seeded wildbean, and trailing wild bean) were established the summer before planting the cool-season species. In autumn, tall fescue and winter-planted legumes (arrowleaf clover, white clover, crimson clover, hairy vetch, alfalfa, Tifton Burr medic, rigid medic, button medic, and little burr medic) were no-till drilled into the existing summer legumes after mowing to a 5-cm height. It was reported that the summer legumes did not regenerate in any of the 3 yr or two locations evaluated, and reseeding of the winter annual legumes was negligible in the first two seasons due to limited rainfall. In the third season, when autumn moisture was sufficient to allow for reseeding, button medic (58%) and little burr medic (55%) had the greatest percentage of stand at Vernon, and arrowleaf clover (49%) and Tifton burr medic (54%) had the greatest percentage of stand and reseeding potential at Vashti. Alfalfa was too competitive with the annual legumes and tall fescue when grown in mixed stands. However, alfalfa and tall fescue could be successfully established in alternating drill rows and a combination of alternating and perpendicular row orientations (referred to as "checkerboard pattern"), while binary mixture (mixed in the same drill row) and perpendicular-only orientations (species planted in different directions) resulted in excessive competition (Butler et al., 2011c). The combination of alternating and perpendicular planting orientation (checkerboard pattern) offered the best potential to minimize preferential grazing while maintaining adequate stand density and persistence in the southern Great Plains. This new technique for establishment may offer potential for forage systems; however, economic data are needed to verify if this new planting technique will translate into greater net returns.

Results focusing on interseeding native herbaceous perennial legumes into existing grass swards have not been much more promising (Muir and Pitman, 2004). Stoloniferous grasses such as bermudagrass (*Cynodon* spp.) are simply too aggressive, and even native bunch grasses such as switchgrass (*Panicum virgatum* L.) usually shade out seedlings during establishment except during high rainfall years. Overseeding cool-season annual legumes onto dormant switchgrass stands holds more promise (Bow et al., 2008), although low yields of legumes may make such systems prohibitively expensive except in high-return systems such as trophy wildlife.

Economics of Grazing Systems

Economic results are fluid and can change rapidly depending on current pricing. For example, if the price of N fertilizer increased dramatically, the results (profitability of legumes) may also change. Grazing monoculture stands of alfalfa with stocker calves in summer is very profitable (US$314 ha^{-1} yr^{-1}) (Butler et al., 2012a) and is comparable to net returns (total income minus total expenses) of grazing stocker calves on rye (*Secale cereale* L.)–ryegrass (*Lolium multiflorum* Lam.) (US$279 ha^{-1} yr^{-1}) during the cool-season (Islam et al., 2011). However, cumulative profits from grazing monoculture alfalfa may not be as high as alfalfa for hay production since the stand life is often reduced by grazing. In other studies (Bates et al., 1996; Butler et al., 2012a), alfalfa has persisted 3 yr under grazing, whereas it typically lasts 4 to 5 yr when harvested as hay. Grazing alfalfa interseeded into perennial grasses can be risky due to establishment issues, especially in areas with limited rainfall. Summer stocker grazing was more profitable when bermudagrass was fertilized with 112 kg N ha^{-1} (US$212 ha^{-1} yr^{-1}) compared to bermudagrass–alfalfa (US$86 ha^{-1} yr^{-1}) mixture (Biermacher et al., 2012). The poor performance of the alfalfa system was attributed to initial stand failure and the cost of re-establishment, the relatively short persistence of alfalfa under grazing, and competition with the bermudagrass. Grazing a bermudagrass–vetch–clover system (US$130 ha^{-1} yr^{-1}) had lower net return than bermudagrass fertilized with N fertilizer (US$212 ha^{-1} yr^{-1}) over 3 yr (Biermacher et al., 2012). In another 3-yr experiment, net return for a tall fescue–vetch–clover–pea system ($93 ha^{-1} yr^{-1}) was lower than tall fescue fertilized with 112 kg N ha^{-1} (US$224 ha^{-1} yr^{-1}) (Interrante et al., 2012). This lack of benefit from the legumes was attributed primarily to limited rainfall that affected legume establishment and grass competition that limited legume production and therefore the amount of N fixed. However, despite this low economic benefit of legume-incorporated compared to N-fertilized systems, another study reported that the net returns of rye–vetch–clover–pea (US$229 ha^{-1} yr^{-1}) was similar to net returns of a rye–ryegrass system (US$282 ha^{-1} yr^{-1}) fertilized with 112 kg N ha^{-1} (Butler et al., 2012b). The annual legume component primarily consisted of hairy vetch, which has the greatest potential in annual forage systems. Livestock avoid grazing hairy vetch early in the season but perform very well once forced to consume it.

LESSONS LEARNED

There are reasons legumes are not widely adopted in forage systems in the southern Great Plains. There are occasions when a legume is identified to have great potential by a group of researchers, only to subsequently find out that no commercial seed company is willing to market it due to undeveloped infrastructure or issues with seed production. For example, several medics that could be useful forages in the southern Great Plains have been identified; however, they require specialized seed harvest equipment (e.g., a Horwood Bagshaw harvester, which is no longer being manufactured). Other legumes may have indeterminate flowering and dehiscent seedpods that make commercial seed production difficult or nearly impossible (Butler and Muir, 2006). Market demand is also often weak, at least initially, so that seed companies are reluctant to invest in a new crop. Even when there is demand, it is often for such small quantities that retailers cannot justify carrying inventory.

Sometimes legume enthusiasts oversell legume economic potential without the necessary socioeconomic studies to back up the hyperbole (Thomas and Sumberg, 1995). This often leads to unfulfilled expectations, since researchers often report high-input, monoculture legume yields and farmers expect those results when combined with grass. As a general guideline, yields of legume grown in competition with grass are half those of from legumes grown in monoculture. In addition, legumes typically require greater amounts of P and K fertilizer, the costs of which have increased drastically over the past years. Often the reduction in N fertilizer cost is nullified by increased cost of limestone, P fertilizer, and K fertilizer.

The most likely reason for lack of forage legume adoption is that farmers and ranchers strive for risk avoidance; unpredictable climates and markets are risk enough. Establishment failures are more common for legumes than for grasses because the latter generally have more vigorous seedlings. Most legume seeds are expensive, difficult to establish, incompatible with grasses, and not well-adapted to a wide range of soils and environments. The only choice a producer using N fertilizer has to make is the application rate, a much easier choice than determining which among several legumes are ideal for his locality and which seeding rates, planting techniques, and associated legume management strategies to use. In recent years, as N fertilizer prices have increased, legumes became a potentially sustainable alternative, but legume seed prices have increased at the same rate and level as N fertilizer, probably from increased demand. This seed price increase often results from greater overall agricultural commodity prices and the increased demand for grain crops. Additionally, greater demand for these legume seeds tends to increase the cost.

The demand for legume seeds by wildlife managers in southern North America is a double-edged sword. If it were not for the wildlife market, there would be even fewer commercially available legumes. However, it is the wildlife market that generally supports the high seed prices. Thus, farmers and ranchers using legumes in their livestock systems cannot compete with the wildlife industry if they plan to be economically sustainable. To overcome this pricing obstacle, they could go back to producing seed on their own land or through local cooperatives, an approach that might solve shortages locally but may limit regional availability even more. Seed companies or university plant breeders often trademark or patent varieties, thereby preventing on-farm seed production. To overcome this issue, particularly with niche legumes, an expensive institutional commitment is needed to ensure adequate seed becomes available to producers. For example, when a new legume species is developed, the research institute or seed company needs to guarantee the infrastructure to develop seed production and processing facilities. Seeking the guidance and support of local growers or extension agencies may enhance bringing promising germplasm into commercial production and retail.

Forage legumes do not always meet the standards or expectations typically used for grass forage systems. Therefore, we must think about legumes differently. The goal should be to identify legumes that are best adapted and find alternative ways to incorporate these into the farming systems to obtain the benefits of greater forage quality and different season of use. The best approach may be to limit use of legumes (in monoculture stands) to the better soils on a given farm and to limit access, similar to a supplementation program during periods of limited forage production. This will obviously require greater management and time commitment, but producers must be realistic in their expectations.

Ongoing and Future Research

Various government and privately funded organizations are currently focused on developing native legume germplasm for native grassland restoration. These include the United States Department of Agriculture Natural Resource Conservation Service Plant Materials Centers, Oklahoma Native Plant Society, South Texas Natives at Texas A&M Kingsville University, and North Texas Ecotype Project at Texas Agrilife Research (formerly the Texas A&M Experiment Station). These entities collect seed in remnant native populations, evaluate accessions in traditional plots, select species and accessions whose seed are easily harvested, and then release them to seed producers in systematic but very unconventional arrangements that bypass university cultivar release committees and have forced state seed certification boards to adopt new classifications (Smith et al., 2010). Usually species are sold in mixes adapted to a wide range of climates and soils and are given quasi-official and poorly defined (by traditional plant breeder standards) classifications such as "Natural Germplasm" or "Source Identified Germplasm." Legumes are among the most important native forbs being domesticated for seed production, and because they are expensive, they are usually sold in predominantly grass seed mixes designed for native grassland or savannah restoration.

The Samuel Roberts Noble Foundation, a southern Great Plains nonprofit organization focused on developing sustainable agricultural and natural resource management systems, is currently working on legume germplasm to identify genes for improved tolerance to biotic and abiotic stresses such as improved drought tolerance, tolerance to low soil pH/high Al^{3+} and low soil P, improved nutritive value via lignin reduction, and the potential to introduce tannin biosynthesis in alfalfa for reduced bloat potential. In addition, evaluations are underway on establishment and management of RoundupReady (glyphosate-tolerant) alfalfa in bermudagrass stands. Production and economic comparisons of tall fescue with commercial N fertilizer and conventional alfalfa–tall fescue systems planted in the checkerboard orientation are also ongoing.

There is also a growing interest in secondary uses of forage legumes in the southern Great Plains. Warm-season perennial legumes are known to contain condensed tannins that affect ruminants in multiple ways, including internal parasite control (Muir, 2011). In the southern United States there is currently some research and commercial interest in legumes as a source of condensed tannins for use within the small ruminant husbandry sector in which industrial anthelmintic-resistant gastrointestinal parasites are problematic (Terrill et al., 2007). The introduced legume sericea lespedeza [*Lespedeza cuneata* (Dum. Cours.) G. Don], which is the main focus of that research, is poorly adapted to the drier, hotter sections of the southern Great Plains. However, legumes native to the southern Great Plains have been reported to have condensed tannins (Muir et al., 2008a), and early research indicates that these legumes are effective at suppressing gastrointestinal parasites in goats (Muir, 2011; unpublished data, 2010).

Due to the economic potential and the limitations of legumes in forage systems, there is great opportunity for researchers to develop legume-inclusive regenerative, semiclosed forage systems on which the future of the southern Great Plains ruminant production could depend (Pearson, 2007). One priority should be to evaluate a much broader range of rhizobia and legume germplasm (Howieson et al., 2000). This approach will likely require additional collection trips, both locally and abroad, and more substantial funding but offers potential long-term sustained benefits for the future. Developing viable weed control options for forage legumes is needed since there are so few options (Butler et al., 2010, 2011b). Another approach is to focus on developing native legumes where productive exotics fail to establish and persist (Muir et al., 2011). More emphasis is needed on research targeting improving seed production potential of these species. Under grazed conditions, increased seed production may improve reseeding potential, while if grown for seed production, high seed yields will make seed for forage establishment more readily available and less expensive. Improved establishment techniques are also needed especially in mixtures with warm-season grasses. Improvement in grazing management (rotational stocking) could improve systems, but combining various systems will likely provide the greatest advantage. For example, instead of interseeding legumes in warm-season perennial grasses, research could focus on evaluating various proportions of monocultures of grass and legume within the same system; this approach would require radically new grazing management strategies such as palatability pairing which would guarantee legume persistence. In addition, more extension education and on-farm demonstrations are needed to illustrate how these systems work in the real world.

CONCLUSIONS

This paper summarizes the legume germplasm evaluation, establishment, management, and grazing production–economic experiments conducted in the southern Great Plains. Several medics and clovers are compatible and can be established with tall fescue; however, due to limited precipitation, annual legumes have not reliably regenerated in permanent grass swards. Hairy vetch has consistently established in perennial grass swards, although it required annual establishment. Hairy vetch was not as economical as N fertilizer in the perennial grass (bermudagrass and tall fescue) systems, but it was the primary component in the annual (rye–ryegrass) system, which was profitable, similar to N-fertilized system. Of the legumes tested, alfalfa may have the greatest potential in cool-season perennial grass systems in the southern Great Plains especially in conjunction with tall fescue when planted in a checkerboard orientation. Alternatively, the best approach may be to limit use of legumes (in monoculture stands) to the better soils on a given farm with limited access, similar to a supplementation program during periods of limited forage production (summer and winter months). There is a need for greater germplasm and rhizobia evaluations as well as a need for seed production, weed control, and grazing research to improve farmer/rancher adoption of legumes. Future research should also improve establishment of legumes, develop management practices that extend the life of legumes in forage systems, and carry out appropriate economic analysis to aid farmers in making decisions regarding adoption of new technology.

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