

Douglas King Seed Company production field of 'Rio Grande' Germplasm (*Acacia angustissima* [prairie acacia]) growing near San Antonio, Texas. Photo by Forrest S Smith

Challenges to developing native legume seed supplies: the Texas experience as a case study

James P Muir, William D Pitman, Forrest S Smith, John Lloyd-Reilley, and Robert A Shadow

ABSTRACT

Plant community biodiversity is critical for maintaining native and cultivated grasslands. Even though legume nitrogen contribution can enhance ecosystem productivity, a critical number of native herbaceous legume species are not commercially available for grassland seed mixes in the south-central US. Of those on the market from other regions, perennial temperate species fail to survive the hot summer seasons, and the tropical species lack sufficient cold tolerance for winter survival through most of the region. We examine historical and current efforts to identify appropriate genotypes to supply native legume seed in Texas and immediate surroundings as a case study for developing a widely under-utilized resource in this and other regions. More than 30 native legume genera occur across this region, often as small, isolated, and protected populations. Several recent native legume releases target forage production, grassland reclamation, and wildlife habitat, but the seed available meets only small-scale demands and lacks diversity. Wider germplasm adaptation, less costly seed production, and improved marketing may increase demand and economic viability of multiple native legume seeds in restoration, right-of-way stabilization, rangeland rehabilitation, and pasture cultivation. Systematic germplasm selection that focuses on potential market, seed harvestability, seedling vigor, and persistence under inter-plant competition and grazing pressures could substantially increase native legume domestication and sustained commercialization. Coordination of seed supply and demand involving policy aspects of government incentive programs, seed industry investments, and extension programs targeting potential user groups could contribute to greater commercialization success of native legumes with potential to provide multiple benefits to ecosystems across North America.

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KEY WORDS

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NOMENCLATURE

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lant species diversity can foster greater stability and sometimes greater productivity in low-input grasslands whether in natural (Tilman and others 2006a), manipulated (DeHaan and others 2009), or cultivated (Sanderson and others 2004) ecosystems. This diversity is a key factor when restoring natural grasslands (Walden and Lindborg 2016), producing forage for animal agriculture and wildlife (Sanderson and others 2007; Rolo and others 2016), or generating biofuel feedstock from grasslands (Tilman and others 2006b; Sanderson 2010). The challenge to increasing grassland diversity is identifying and acquiring the necessary diverse germplasm when establishing cultivated pasture, restoring degenerated rangeland, or re-establishing native grasslands. Although some progress has been made in domesticating native grasses in the southern Great Plains of North America in recent years (Vogel 2000; Smith and others 2010), providing equivalent legume diversity in seed mixes has been less successful. Commercially available, introduced, cool-season legumes typically fail to survive harsh summer weather, while available tropical legumes are not adapted to the cold winter conditions.

Native legumes in the southern US, adapted to cold winters and hot summers, offer an alternative to poorly adapted tropical or temperate species. Existing populations of herbaceous native legumes in the region are generally localized and decreasing in occurrence as natural areas and extensively managed lands are challenged (for example, over-grazed and protected from fire) or converted to other uses, although limited disturbance can result in greater legume presence (Ruthven 2006). Widespread interest in the native legumes of warm-temperate and subtropical regions of North America is rather recent. Impetus has been provided by increases in, and volatility of, nitrogen fertilizer prices as well as a growing interest in pasture diversity primarily for wildlife habitat (Smith and others 2010). Numerous summer-growing, herbaceous, perennial legumes are native to south-central US, as noted for portions of the region by Diggs and others (1999) and Thomas and Allen (1998). These species include unique adaptations to freezing winters and extremely dry, hot summers (Noah and others 2012a). There is no long-term history of domestication of these species, which limits commercialization because very few have been traded in the seed industry. Extended flowering periods combined with aggressive natural seed dispersal limit seed recovery from single-harvest protocols (Muir and others 2005a, 2005b). Low seed germination rates as a result of hard-seededness (Pitman 2009; Dittus and Muir 2010) can cause poor stand establishment. These characteristics, which are advantageous for native legume survival in natural ecosystems, can present limitations to commercial domestication. A modicum of domestication is required to create germplasm capable of overcoming these production shortcomings.

NATIVE LEGUMES OF THE TEMPERATE RANGELANDS OF CENTRAL AND WESTERN OKLAHOMA AND TEXAS

The extensive natural grasslands in central and western Oklahoma and Texas include substantial legume diversity with substantial adaptation to summer drought. Diggs and others (1999) listed more than 30 distinct herbaceous and shrubby legume genera native to north-central Texas. To date, only a fraction of these have been considered for domestication. Even fewer of the native arboreal or semi-arboreal legumes (Vines 1960; Diggs and others 1999) have been examined. Initial domestication efforts involving this leguminous resource in the south-central US were led by the Natural Resources Conservation Service (NRCS; then SCS) Plant Materials Center at Knox City, Texas. A major part of the early efforts involved Desmanthus (bundleflower [Fabaceae]) species (Anonymous 1984; USDA NRCS 2011b). (Note that unless specified otherwise, species discussed are from the Fabaceae family.) Additional early germplasm enhancement efforts led to releases of Leucaena retusa Benth. (Yellowpuff littleleaf leadtree [USDA NRCS 2006]), Dalea purpurea Vent. (Cuero purple prairie clover [Lindgren and Schaaf 2003; USDA NRCS 2003]), and Chamaecrista fasciculata (Michx.) Greene (Comanche partridge pea [TAES 1986]). Table 1 has a complete list of native legume germplasm releases for the southern Great Plains and western Coastal Plain. More recent collections and evaluations have involved the NRCS programs with a native legume emphasis at the Texas A&M AgriLife Center at Stephenville, Texas, and at South Texas Natives at Texas A&M University at Kingsville, Texas.

Agronomic evaluations of Acaciella, Desmanthus, Desmodium, Galactia, Lespedeza, Neptunia, Rhynchosia, and Strophostyles spp. at Stephenville, Texas, demonstrated varying levels of forage potential and value for conservation uses (Packard and others 2004; Muir and others 2005a, 2005b; Muir and Bow 2008; Muir and others 2008; Muir and others 2009; Noah and others 2012a, 2012b) (see Table 1). Additional species targeted for collection and screening evaluations by the Plant Materials Center at Knox City over the years include some species not represented by releases but that are now available commercially, such as Amorpha canescens Pursh (leadplant) and Dalea candida Michx. ex Willd. (white prairie clover). Released varieties or germplasms with adaptation to at least some sites within the region (listed in Table 1) have multiple uses including habitat and food for wildlife, reclamation of disturbed sites, native ecosystem restoration, and forage (rangeland and cultivated pasture) for grazing livestock.

Untapped resources for domesticating regionally native legumes are considerable. Observations and preliminary evaluations indicate significant potential developing useful germplasm for several additional native legumes (species listed in

Official releases of native legume (Fabaceae) germplasm for the southern Great Plains and western Coastal Plain.

| Latin binomial | Common name | Release name | Domestication | Source/Location ^z |
|---|---------------------------|--------------|-------------------|------------------------------|
| HERBACEOUS | | | | |
| Acacia angustissima var. hirta (P. Mill.) Kuntze (Acaciella angustissima (Mill.) Britton & Rose) | Prairie acacia | Rio Grande | Germplasm release | NRCS-EKGPMC/STN |
| | | Plains | Germplasm release | NRCS-JEBSPMC/TAMAR |
| Chamaecrista fasciculata (Michx.) Greene | Partridge pea | Comanche | Conservation | NRCS-JEBSPMC |
| | | Riley | Conservation | NRCS-KSPMC |
| Dalea purpurea Vent. | Purple prairie clover | Cuero | Germplasm | NRCS-JEBSPMC |
| | | Kaneb | Conservation | NRCS-KSPMC |
| Desmanthus illinoensis (Michx.) MacM. | Illinois bundleflower | Sabine | Germplasm | NRCS-JEBSPMC |
| | | Reno | Germplasm | NRCS-KSPMC |
| Desmanthus velutinus Scheele | Velvet bundleflower | Hondo | Conservation | NRCS-JEBSPMC |
| Desmanthus virgatus (L.) Willd. var. depressus (Willd.) B.L. Turner | Prostrate bundleflower | Balli | Germplasm | NRCS-EKGPMC/STN |
| Desmodium paniculatum (L.) DC | Panicledleaf tick-trefoil | n/a | Germplasm | TAMAR |
| Lespedeza capitata Michx. | Roundhead lespedeza | Kanoka | Conservation | NRCS-KSPMC |
| Mimosa strigillosa Torr & A. Gray | Herbaceous mimosa | Crockett | Germplasm | NRCS-ETPMC |
| Strophostyles helvola (L.) Elliott | Trailing wildbean | n/a | Developing | TAMAR |
| Strophostyles leiosperma Torr. & A. Gray | Smooth-seeded wild bean | Rio Rojo | Cultivar | TAMAR |
| Vicia ludoviciana Nutt. | Deer pea vetch | Hoverson | Germplasm | NRCS-ETPMC/STN |
| SHRUB | | | | |
| Leucaena retusa Benth. | Littleleaf lead tree | Yellowpuff | Germplasm | NRCS-JEBSPMC |
| Styphnolobium affine (Torr. & A. Gray) Walp. | Eve's necklacepod | n/a | Developing | TAMAR |

^zSTN, South Texas Natives, Caesar Kleberg Wildlife Research Institute, Texas A&M Kingsville, Kingsville, TX USA; TAMAR, Texas A&M AgriLife Research, Stephenville, TX USA; NRCS-EKGPMC, USDA NRCS, E "Kika" de la Garza Plant Materials Center, Kingsville, TX USA; NRCS-JEBSPMC, USDA NRCS, James E "Bud" Smith Plant Materials Center, Knox City, TX USA; NRCS-ETPMC, USDA NRCS, East Texas Plant Materials Center, Nacogdoches, TX USA; NRCS-KSPMC, USDA NRCS, Manhattan Plant Materials Center, Manhattan, KS.

Table 2). These legumes represent a substantial range in attributes that make them attractive in habitat and range improvement. Some species show unique adaptations that produce tolerance to grazing. Many are erect in habit and some are highly palatable (Sheaffer and others 2009). Rhizomatous growth of Acaciella angustissima (Mill.) Britton & Rose (prairie acacia) and stoloniferous habit of Mimosa strigillosa Torr. & A. Gray (herbaceous or powderpuff mimosa) provide mechanisms for defoliation tolerance, which have been documented in other rhizomatous legumes, such as Arachis pintoi Krapov. & W.C. Greg. (pinto peanut) (Ibrahim and Mannetje 1998). Legumes with prostrate growth habits, such as Neptunia lutea (Leavenworth) Benth. (yellow puff), may avoid cattle (but not small ruminant) herbivory by developing structural stems close to the soil surface. Astringency resulting from condensed tannin content (Muir and others 2005b; Jin and others 2012) may also play a role in persistence. Most of the germplasm under evaluation in these programs are adapted to mid-grass and tall-grass prairie in Texas and Oklahoma where historical tolerance of

periodic bison grazing was essential to survival (Jackson and others 2010). Many of the leguminous species derived from north Texas and Oklahoma are adapted to environments farther north into the Central Great Plains. This expansion provides enhanced markets and greater potential for profitable commercialization.

NATIVE LEGUMES OF SUBTROPICAL SOUTHERN TEXAS

Native legumes of southern Texas have evolved in an environment with a long growing season and limited cold stress, conditions that provide unique adaptation characteristics. Development of this germplasm resource has been much more recent than that from central and northern Texas. Ocumpaugh and others (2003) obtained initial commercial success with germplasm derived in this region with *Desmanthus bicornutus* S. Watson (two-horn bundleflower). Three additional species have recently been released through efforts of South

Native legume (Fabaceae) germplasm of the southern Great Plains and western Coastal Plain being evaluated for potential domestication.

| Latin binomial | Common name | Source/Location ^z |
|---|---------------------------|-----------------------------------|
| HERBACEOUS | | |
| Chamaecrista fasciculata (Michx.) Greene | Partridge pea | STN/NRCS-EKGPMC |
| Chamaecrista flexuosa (L.) Greene | Texas sensitive pea | STN |
| Dalea aurea Nutt. ex Pursh | Golden prairie clover | STN/NRCS-EKGPMC |
| Dalea candida Michx. ex Willd. | White prairie clover | STN/NRCS-EKGPMC |
| Dalea compacta Spreng. | Compact prairie clover | STN |
| Dalea emarginata (Torr. & A. Gray) Shinners | Wedgeleaf prairie clover | STN |
| Dalea multiflora (Nutt.) Shinners | Roundhead prairie clover | TAMAR-Stephenville NRCS-EKGPMC |
| Dalea nana Torr. ex A. Gray | Dwarf prairie clover | STN/NRCS-EKGPMC |
| Dalea obovata (Torr. & A. Gray) Shinners | Pussyfoot | STN/NRCS-EKGPMC |
| Dalea pogonathera A. Gray var. walkerae (B. Tharp & F.A. Barkley) B.L. Turner | Bearded prairie clover | STN/NRCS-EKGPMC |
| Dalea scandens (Mill.) R.T. Clausen | Low prairie clover | NRCS-EKGPMC |
| Desmanthus illinoensis (Michx.) MacMill. ex B.L. Rob. & Fernald | Illinois bundleflower | STN |
| Desmodium nuttallii (Schindl.) B.G. Schub. | Nuttall's tick trefoil | TAMAR-Stephenville |
| Desmodium paniculatum (L.) DC. | Panicledleaf tick trefoil | TAMAR-Stephenville |
| Galactia canescens Benth. | Hoary milkpea | STN |
| Indigofera miniata Ortega | Scarlet pea | TAMAR-Stephenville |
| Lespedeza stuevei Nutt. | Tall lespedeza | TAMAR-Stephenville |
| Macroptilium atropupureum (Moc. & Sessé ex DC.) Urb. | Purple bushbean | NRCS-EKGPMC |
| Neptunia lutea (Leavenworth) Benth. | Yellow puff | STN/NRCS- TAMAR-Stephenville |
| Neptunia pubescens Benth. | Tropical puff | STN |
| Rhynchosia latifolia Nutt. ex Torr. & A. Gray | Prairie snoutbean | LSU AgCenter |
| Senna roemeriana (Scheele) Irwin & Barneby | Twoleaf senna | STN |
| Strophostyles helvola (L.) Elliott | Trailing wildbean | TAMAR-Stephenville |
| Stylosanthes viscosa (L.) Sw. | Poorman's friend | NRCS-EKGPMC |
| Tephrosia lindheimeri A. Gray | Lindheimer's hoarypea | STN |
| Vigna luteola (Jacq.) Benth. | Wild cowpea | NRCS-EKGPMC |
| SHRUB | | |
| Acacia berlandieri/Senegalia berlandieri Britton & Rose | Guajillo | STN |
| Acacia greggii var. greggii/Senegalia greggii (A. Gray) Britton & Rose | Catclaw acacia | STN |
| Acacia greggii var. wrightii/Senegalia wrightii (Benth.) Britton & Rose | Catclaw acacia | STN |
| Acacia rigidula/Vachellia rigidula (Benth.) Seigler & Ebinger | Blackbrush acacia | STN |
| Acacia schaffneri/Vachellia schaffneri (S. Watson) Seigler & Ebinger | Shaffner's wattle | STN |
| Acacia smallii/Vachellia farnesiana (L.) Wight & Arn. | Sweet acacia | STN |
| Calliandra conferta Benth. | Pink mimosa | STN |
| Coursetia axillaris J.M. Coult. & Rose | Texas babybonnets | STN |
| Eysenhardtia texana Scheele | Texas kidneywood | STN |
| Indigofera suffruticosa Mill. | Anil de pasto | STN |
| Mimosa texana (A. Gray) Small | Texas mimosa | STN |
| Pithecellobium ebano (Berl.) Barneby & Grimes | Texas ebony | STN |
| Pithecellobium/Havardia pallens (Benth.) Britton & Rose | Haujillo | STN |
| Prosopis reptans Benth. | Tornillo | STN |
| Styphnolobium affine (Torr. & A. Gray) Walp. | Eve's necklace | TAMAR-Stephenville |

² STN, South Texas Natives, Caesar Kleberg Wildlife Research Institute, Texas A&M Kingsville, Kingsville TX USA; TAMAR, Texas A&M AgriLife Research, Stephenville

TX USA; NRCS-EKGPMC, USDA NRCS, E "Kika" de la Garza Plant Materials Center, Kingsville TX USA. 228



Plants of Rio Grande Germplasm (*Acaciella angustissima*) with mature seed pods growing in a Douglas King Seed Company production field near San Antonio, Texas. Photo by Forrest S Smith

Texas Natives and the USDA NRCS E. "Kika" de la Garza Plant Materials Center (Smith and others 2010). These include Balli Germplasm *Desmanthus virgatus* (L.) Willd. (prostrate bundleflower [USDA NRCS 2013]), Hoverson Germplasm *Vicia ludoviciana* Nutt. (deer pea vetch), and Rio Grande Germplasm *Acaciella angustissima* (prairie acacia). Balli Germplasm and Rio Grande Germplasm have been commercialized, and seed is used in restoration seed mixes with regionally adapted native grasses.

South Texas Natives at Texas A&M Kingsville has evaluated additional native legumes; however, most lack seed production potential for profitability given current harvest methods and customary seed production systems. Concerns over market size, related to limited natural distributions and potential areas of adaptation, are also inherent problems that hinder commercial success of products from these germplasm sources. New species being evaluated and considered for commercialization include Dalea multiflora (Nutt.) Shinners (roundhead prairie clover), Tephrosia lindheimeri A. Gray (Lindheimer's hoarypea), Galactia canescens Benth. (West Indian milkpea or Hoary milkpea), and Neptunia pubescens Benth. (tropical puff). Interest in these species centers around wildlife habitat, namely as seed-bearing food plants and hosts for arthropods that are consumed by Northern Bobwhites (Colinus virginianus [Odontophoridae]) or as potential forages of benefit to white-tailed deer (Odocoileus spp. [Cervidae]). The released plants are used



Flowers of Acaciella angustissima. Photo by Shelley D Maher

in some cases by the Texas Department of Transportation as low-growing plant species for roadside revegetation.

NATIVE LEGUMES OF THE HUMID EASTERN AREA

As in southern Texas, collection and evaluation of native legumes from the humid eastern portion of the region has a limited history. A list of native legumes of adjacent Louisiana includes 135 species with most of these growing as herbaceous perennials (Thomas and Allen 1998). Potential value of the native legumes in this widely forested, humid area is illustrated by continuing progress with the evaluation of herbaceous mimosa. Value for conservation uses led to the release of Crockett Germplasm herbaceous mimosa by the East Texas Plant Materials Center (USDA NRCS 2012b). Herbaceous mimosa is recognized as particularly appropriate for reclamation purposes (Chang and others 1995, 1997; Nuruddin and Chang 1999).

Only a few species from this area have been subjected to initial screening. Forage potential has been indicated for *A. angustissima, Desmodium paniculatum* (L.) DC. (panicledleaf ticktrefoil), and *Rhynchosia latifolia* Nutt. ex Torr. & A. Gray (prairie snoutbean) in eastern Texas and Louisiana (Pitman 2009; Noah and others 2012a, 2012b). The *A. angustissima* and *D. paniculatum* accessions evaluated were originally collected



Low-growing habit of the prostrate *Desmanthus virgatus*. Photo by Forrest S Smith



Todd Jenschke inspecting an evaluation plot of Hoverson Germplasm (*Vicia ludoviciana*) growing on the South Texas Natives Project Farm at the 230 Caesar Kleberg Wildlife Research Park near Kingsville, Texas. Photo by Forrest S Smith



Plant in habitat of Dalea multiflora. Photo by Kasia Olczak

in drier environments in Texas, which indicates adaptation and usefulness in this high rainfall area of some materials already selected and increased in the western and (or) southern portions of Texas. *Rhynchosia latifolia* was superior to other Louisiana legumes evaluated in colonization potential on upland sites (Pitman 2009).

CASE STUDIES OF RECENTLY DOMESTICATED NATIVE LEGUMES

Desmanthus illinoensis (Michx.) MacMill. ex B.L. Rob. & Fernald (Illinois bundleflower) cultivar 'Sabine' provides an initial native legume domestication success story from the region. This cultivar resulted from seed collected in Texas by SCS (now NRCS) personnel in 1971 (TAES 1984; Muncrief and Heizer 1985). 'Sabine' was evaluated by the USDA SCS in cooperation with the Texas Agricultural Experiment Station and Texas Parks and Wildlife Department (Anonymous 1984) at multiple locations in Texas and Oklahoma and compared with plants from other seed collections from sites across the 2 states. Superior leafiness, which contributes to enhanced forage nutritive value, and seed production were important selection criteria. Subsequent low cost and seedling vigor have led to wide use. Initial commercial seed availability was particularly enhanced by efforts of Arnold G Davis, who had been involved in release of the material as an SCS employee. After his retirement, he continued to facilitate commercialization of the cultivar in the 1980s through his company, Prairie Enterprises, located in Fort Worth, Texas. Seed of Sabine Illinois bundleflower has been available from multiple commercial seed sources for almost 3 decades. Plantings have been made for wildlife food, reclamation of disturbed sites, and forage (Schweitzer and others 1993; Muir and Pitman 2004).

Four *D. bicornutus* selections BeeTAM-06, BeeTAM-08, BeeTAM-37, and BeeTAM-57 (Ocumpaugh and others 2003; Ocumpaugh and others 2004a,b,c,d) came from Australian



Texas A & M University graduate student Gulten Girgin collecting soil samples for pH preference determination within a native population of *Dalea multiflora*. Photo by Kasia Olczak

repositories but were originally collected in Mexico. These were licensed for exclusive marketing as a blend called 'BeeWild bundleflower.' Unlike Illinois and velvet bundleflower, which have sufficient cold tolerance for use in warm temperate climates, D. bicornutus has limited frost tolerance restricting it to warmer tropical and subtropical regions. Its popularity arose from low seed costs because of abundant seed set, aggressive seedlings, coppicing regrowth after heavy browsing or frost damage, and abundant seedling recruitment. The primary uses of BeeWild are seed and food resources for wildlife, especially in food plot settings, though pasture plantings are also common. The commercial blend has proven problematic for some uses because of its large stature, the persistent nature of the previous year's growth that can puncture vehicle tires particularly after shredding, and the spreading nature of the species on some soils. BeeWild can exclude grasses as stands develop, but intense grazing or mowing can reduce this propensity. Several seed companies in the region also offer other D. bicornutus selections, likely progeny from Australian cultivars of the species.

Balli Germplasm is a selection of an especially vigorous and upright growing *D. virgatus* population. It has greater seed yields and biomass production than do 'Sabine' and 'Hondo' when grown in southern Texas (Falk and others 2012). This selection was released through the South Texas Natives and "Kika" de la Garza Plant Materials Center germplasm development



Seed pods of Acaciella angustissima. Photo by Shelley D Maher

effort (Lloyd-Reilley and Maher 2013) and has been commercialized for seed production near San Antonio, Texas. It is used in reclamation and wildlife habitat seedings in the Rio Grande Plain and Gulf Coast Prairies and Marshes of southern Texas. Interest in the plant focuses on reseeding rangelands for whitetailed deer and seed for Northern Bobwhites. Recent interest has also developed for pollinator habitat. The selection has good competitive ability, with most of the introduced grasses planted in southern Texas, such as *Dichanthium annulatum* (Forssk.) Stapf. (Kleberg's bluestem [Poaceae]) and *Pennisetum ciliare* (L.) Link (buffelgrass [Poaceae]).

Hondo Germplasm is a selection of *D. velutinus* by the USDA NRCS Knox City Plant Materials Center (USDA NRCS 2011a). This species has not been substantially commercialized, in part because of low supplies of foundation seed material and concern over limited market demand for the species. *Desmanthus velutinus* tends to be restricted to shallow, unproductive sites that are substantially unchanged from their native states. Palatability of this species for livestock and wildlife and seed consumption by wildlife are generally assumed to be poorer when compared with other native bundleflowers. Indeterminate growth and erratic seed shatter are also problems for commercialization, although efforts to commercialize are being undertaken by at least 2 Texas seed companies.

Acaciella angustissima (prairie acacia) is a semi-woody subshrub native through the region and in neighboring states to the north and west (Diggs and others 1999). Clusters of this plant arise from rhizomatous growth, which provides an effective means of local propagation. Early interest in domestication of this species was limited by infrequent seed availability in many natural populations despite natural seed retention in mature pods. Erratic flowering, poor seed set, and seed predation by insects were each identified as a limitation to seed availability in specific situations. Large field collections of ripened pods generally provided very few, if any, viable seed.

Prairie acacia accessions have been collected across much of Texas, and selections have been identified. Seventeen accessions collected across central and northern Texas were selected and composited to form the Plains Germplasm release (USDA NRCS 2008). Another NRCS release, Rio Grande Germplasm (USDA NRCS 2012a) from southern Texas, became commercially available in 2016. Subsequent evaluations revealed wide adaptation across Texas and Louisiana (Noah and others 2012a, 2012b). Development of seed supplies and forage potential indicate that this is a promising native legume.

Mimosa strigillosa (herbaceous mimosa) has a wide geographic range with natural populations reported from disturbed and undisturbed sites. Populations have been observed just east of the region on west-central Mississippi clay wetlands (Burkett and others 2005), along moist roadsides and ditches in humid central and southern Louisiana (Correll and Correll 1941), in seasonally flooded bottomland of central Louisiana (Brown 1943), at the transition between the Gulf Prairie and Marsh area and the South Texas Plains (Chamrad and Box

1968), along the South Texas gulf coast (Sheffield 1983), and in the Rio Grande Region of Texas (Johnson 2006). On poor sites, particularly with limited competition, growth of this legume is often prostrate with potential value only evident as a ground cover. Initial interest in domesticating this plant was related to potential for soil cover, reclamation, and erosion control. Identification by Chamrad and Box (1968) as a "high priority forage plant" for white-tailed deer in southern Texas was later confirmed by Sheffield (1983). Potential productivity of this low-growing, stoloniferous plant was not recognized until Noah and others (2012a) found that herbage dry matter production of the dense, low growth of Crockett Germplasm herbaceous mimosa (USDA NRCS 2012b) exceeded that of other much taller native legumes being evaluated. In mixture with bermudagrass on Louisiana bottomland, growth of herbaceous mimosa has exceeded a height of 40 cm (16 in), which indicates substantial production potential for dense stands. Forage nutritive value has also been sufficient to improve diets of herbivores grazing warm-season perennial grass pastures and rangelands



Flowers and foliage of Mimosa strigillosa. Photo by Kasia Olczak

of the region (Noah and others 2012a). Ongoing evaluations at the LSU AgCenter Red River Research Station near Bossier City, Louisiana, documented acceptability of herbaceous mimosa forage to grazing cattle, tolerance of the plant to grazing defoliation, and continuing stand improvement during the initial years following pasture planting even when subjected to moderate grazing pressure.

The potential uses of herbaceous mimosa include the initially recognized conservation roles, forage plantings in pastures and rangeland, roadside vegetation, and as a wildlife food plant. In addition to the reported value as forage for white-tailed deer in some environments, food plantings have been proposed for wild turkey (USDA NRCS 2012b) with the vegetation, seed, and associated arthropods all potentially contributing to turkey diets. Also, value for pollinator habitat is suggested by observations of substantial bee activity in heavily blooming seed-increase fields. Strategic mowing can stimulate flowering over a substantial portion of the growing season, which can contribute to both seed harvest and pollinator habitat. Along with clipping at early bloom to synchronize flowering, strategic irrigation and levelled fields have contributed to combine harvest of seed from this low-growing plant at the East Texas Plant Materials Center at Nacogdoches, Texas.

TRAITS COMMON TO SPECIES WITH POTENTIAL FOR DOMESTICATION

There appear to be some biological traits common to many successfully commercializing native, herbaceous germplasms. These traits can guide botanists, rangeland scientists, and agronomists who are seeking new germplasm for domestication.

Market: If demand for seed already exists or is predicted, costs and benefits of developing seed sources may favor invest-

ment in certain species from specific environments.



Close up of the flower cluster of *Mimosa strigillosa*. Photo by Kasia Olczak



- **Seed easily harvested:** Abundant seed production from upright plants and non-dehiscent pods favoring easy mechanical harvest may keep seed costs low and supplies abundant. This characteristic also endears them to wildlife managers looking for renewable game-bird feed.
- **Hard seed:** Long-lived soil seedbanks are an asset in regions with unpredictable precipitation or periodic overgrazing. In commercial seed mixes, a portion of the legumes can be scarified for immediate germination following planting while the remainder can contribute to the soil seedbank.
- **Aggressive seedling:** Plants that establish quickly following planting or that recruit new plants in established stands make species appealing to land managers, especially in competition with fast-growing stoloniferous or rhizomatous grasses. This aggressiveness, however, can lead to invasiveness that, if not heavily browsed or mowed, can exclude other plant species. Mixing pioneer annuals characterized by large seeds and aggressive seedlings, such as *Strophostyles* spp., with slow-establishing perennial legumes could mitigate establishment failures.
- **Tolerance of herbivory:** Once established, grazing and browsing tolerance is an asset in herbivory-intensive ecosystems, such as continuously grazed rangeland or areas with heavy white-tailed deer populations. These include spineferous or woody stems that discourage herbivory, prostrate or arboreal growth habits that escape ruminants, and fast regrowth that re-establishes photosynthetic material quickly. Although high plant nutritive value (protein or digestible energy) are assets for wildlife and domesticated stock, biochemical traits, such as condensed tannins whose content in leaf material plants can increase under heavy herbivory, can mean the difference between extirpation and long-term adaptation to ruminants.
- Wide environmental adaptation: Native legumes with wide genetic variability are more likely to establish and persist in diverse soils, climates, plant communities, and management. Using modern genome sequencing techniques, such as rad seq, to characterize genetic variability from field collections across regions or, ideally, an entire genome, can save years of phenotypic observation in microplots. These techniques can be used to select a single adaptable ecotype or a range of ecotypes adapted to various environments, depending on objectives. Commercial success is enhanced when seed targets geographically specific or broad markets.

MARKET POTENTIAL AND LIMITATIONS

Market demand for newly domesticated and commercialized native legumes depends on many factors. Understanding their value in natural and managed ecosystems is a first step: Why bother purchasing expensive native seed mixes with a multitude of legume species when options based on a single introduced species are far less expensive and less complicated to seed and establish? Land manager objectives will dictate the answer. If establishing self-sustaining, stable ecosystems is the goal, then diverse native seed mixes should include numerous legume species.

Economic success of a native legume selection is dependent on the willingness of a seed company to risk the cost of production and market development. Kupzow (1980) noted the requirement of an economic advantage over existing options for successful domestication of additional species, and this was still true 30 y later (Smith and others 2010). Federal and state government conservation programs and environmental, transportation, and wildlife agencies (for example, TxDOT 2016) provide crucial incentives for marketing native legume species. By suggesting and sometimes even requiring natives in seed mixtures, these entities provide an initial small-scale demand that seed companies can then expand into privatesector markets, such as ornamental horticulture, wildlife and pollinator habitat, reclamation, and rangeland rehabilitation. Uses for domesticated native legumes with adaptation across regions contrasts with a demand for local ecotypes of native species for re-establishment of natural ecosystems. For the latter, exclusively local ecotypes from the site of origin or adjacent naturally existing populations can be advantageous when the goal is to safeguard local biodiversity and genetic composition (Gustafson and others 2004). Genomic sequencing that characterizes species' genetic variability can guide just how local ecotypes need to be.

Existing markets for seed of some native legumes in the region are currently largely maintained by plantings for beautification of areas ranging from home sites to roadsides. These legumes include Lupinus texensis Hook. (Texas bluebonnet) and Lupinus subcarnosus Hook. (sandyland bluebonnet) used on highway roadsides in Texas. Wildlife habitat plantings have recently contributed a substantially expanding market for native legume seed. Revegetation of disturbed lands is a recognized role for some species, particularly the dense-growing, stoloniferous herbaceous mimosa (Norcini and Aldrich 2007). Extensive planting of these legumes on both rangelands and pastures of introduced, warm-season, perennial grasses provides tremendous potential for both economic and environmental benefits. Habitat improvement for game species in some instances primarily provides social and environmental benefits when private hunting, wildlife viewing opportunities, and local species preservation are specific objectives. In other cases, wildlife habitat plantings have direct economic benefits, such as wildlife population enhancement in commercial hunting enterprises. Most of the native legume species at various stages of evaluation and development within the region have potential value to provide biologically fixed nitrogen and/or forage of high nutritive value.

Legumes can improve forage nutritive value and financial return vis-á-vis introduced, warm-season, perennial grass pastures (Muir and others 2014). Potential usefulness within extensive rangelands is less obvious. While plant diversity of most rangelands across the southern Great Plains is a distinct characteristic, the herbaceous plant diversity is often primarily grasses. Palatable forbs, including most native legumes, have been extensively suppressed by selective grazing, herbicides used for broadleaf weed and brush control, and reduced fire frequency. Despite diversity, functional diversity is often low. Enhanced functional diversity from increased populations of native legumes can improve wildlife habitat and increase atmospheric nitrogen fixation in high-quality forage. In addition, functionally diverse grasslands have been recognized as more stable and less susceptible to invasion (Tilman and others 2006a; Picasso and others 2008; Bonin and Tracey 2012). Perhaps a combination of increased functional diversity and appropriate fire frequency could reduce the susceptibility of some of these rangelands to brush encroachment. Some woody legume species are major components of current brush problems, so species selection will be important. Even without considering the contributions of increased functional diversity, rangeland reseeding in the US, which has primarily involved grass species, has resulted in beneficial conservation effects including improved water quality and quantity, reduced soil erosion, and soil carbon sequestration in addition to increased biomass availability as forage (Hardegree and others 2016).

In the south-central US, 2016 prices of native legume seed ranged from US\$ 4 per kg (\$1.80/lb) for the annual partridge pea to US\$ 660 per kg (\$300/lb) for roundhead lespedeza with even higher prices for some seed marketed in small packets for ornamental plantings. Periodic government conservation programs have encouraged larger scale planting of some species by providing substantial cost-sharing, but such programs often do not allow sufficient time to develop adequate seed supplies to meet rather sudden increases in demand. Thus, supplies become erratic, and any resulting increases in supply can be met with inadequate demand as cost-sharing programs sometimes end abruptly. Recent implied need for seeds of pollinator plants is a poignant example of this scenario. Consolidation within the seed industry (Howard 2015) further complicates timely seed provision, as large multinational corporations are often less aware of, or responsive to, small-market seed opportunities previously addressed by the once numerous small, familyowned seed companies. Furthermore, because of isolation requirements and to prevent contamination between germplasm of the same species, production of any single entity is often practically restricted to the best selection across multiple environments.

The intended use of native species affects both the appropriate source of seed and the market potential for this seed. Such varied uses have led to different germplasm release classifications as described by Jones and Young (2005). Commercial potential of germplasm represented by the various releases differs distinctly among classifications. Germplasm intended only for market as "source-identified" seed will have a very limited primary application area and a correspondingly high price to offset collection and processing costs of small seedlots. Harvest must be closely coordinated with time of planned use for timely seed availability. "Select" seed is a step beyond and can supply small-scale regional markets. Such uses as landscape plantings, natural area plantings, and small-scale wildlife habitat plantings, which may justify the high cost of local seed supplies, will likely provide insufficient demand to support a market in which seed price is established according to production cost of field scale operations and bulk mechanical processing and handling. Such scale and seed pricing of widely adapted commercial cultivars will be necessary for extensive planting of native legumes as forage for livestock.

In addition, developing economical seed supply requires selection of agronomically suitable genotypes. Total seed production and harvested yields in seed production enterprises can differ greatly. Poor seed recovery during harvest limits some promising species (Muir and others 2014). Indeterminate flowering, seed shattering, and adaptations for seed ejection



Flowering branch of *Dalea obovata* (pussyfoot), a common species on Texas coastal sands. Photo by Shelley D Maher

from pods are challenging aspects of mechanized seed production. Plant stature and growth habit are other challenging aspects of seed production for many native legumes. Agronomic treatments, such as clipping or burning, may enhance flowering and seed production of some species, or at least provide some synchronization of flowering and seed maturation. Many desirable legume species have vining or decumbent growth forms, producing harvest difficulties with equipment designed for upright perennial grasses.

STEPS TO SELECTING SUPERIOR GERMPLASM FOR DOMESTICATION

Early systematic biological or agronomic evaluation may avoid future challenges to commercialization. Every target ecosystem (native grassland, rangeland, cultivated pasture) is unique and species have numerous characteristics that make generalization difficult, but guidelines could include:

- 1. Understand species' function within their natural settings; these could determine future contribution to the target ecosystem and ensure that diverse ecosystem functions are covered in eventual commercial seed mixes.
- 2. Select among species that anatomically lend themselves to abundant and easy mechanical seed harvest.
- 3. Screen for agronomic characteristics that promise:
 - High seedling vigor
 - Competitive growth within multi-species plant communities
 - Tolerance to grazing or browsing
 - Long-term persistence in harsh environments or poor management
- 4. Bring commercial partners into the process sooner rather than later.
- 5. Provide technical seeding and management packages to seed companies and outreach agencies.

SUMMARY

Although a number of named releases representing several native legume species are listed in Table 1, very limited commercial experience has accumulated. Most of the varieties have been developed so recently that seed production capacity has not yet built up enough to approach economic quantities for extensive commercial pasture and rangeland planting. Seed cost of even the most widely available forage cultivar, Sabine Illinois bundleflower, is sufficiently high to restrict widespread, large-scale planting primarily to a minor component of diverse seeding mixtures. Subsidized conservation plantings, smallscale wildlife habitat plantings, community-based natural area plantings, and even landscape plantings have combined to provide sufficient demand to maintain prices beyond the reach of most agricultural uses on a large scale, such as pastures and rangelands for livestock production. A few seed companies within the southern Great Plains produce seed of a limited number of native legume species. Some commercial harvesting and marketing of seed collected from natural populations also occurs. These sources provide a foundation for a native legume seed industry in the region, although current seed supply and demand do not approach the potential for sustainable markets.

Of the varieties from the region already released, only cultivars are officially recognized as domesticated plant species. In fact, the source-identified release category is specifically managed to prevent either intentional or inadvertent genetic modification so that naturally occurring genetic purity and variation are maintained. Such precaution for revegetation of natural areas is needed because repeated propagation alone with no intentional selection can modify populations. Evaluation, selection, and propagation efforts to date represent only the very beginning of the plant domestication process for native legumes in Texas and the region. None of the releases listed in Table 1 have been the product of genetic modification through plant breeding. Considering the tremendous potential for welladapted, highly nutritious, nitrogen-fixing plants for multiple uses in land reclamation, livestock forage production, wildlife habitat, and other uses, multiple successful legume commercialization of several highly useful domesticated legume species can eventually be expected from current efforts with native legume evaluation and development in the south-central US.

REFERENCES

- Anonymous. 1984. Sabine Illinois bundleflower, a warm-season perennial legume. Publication no. L-2124. College Station (TX): Texas Agricultural Experiment Station.
- Bonin CL, Tracy BF. 2012. Diversity influences forage yield and stability in perennial prairie plant mixtures. Agriculture, Ecosystems and Environment 162:1–7.
- Brown C. 1943. Vegetation and lake level correlations at Catahoula Lake, Louisiana. Geographical Review 33:435–445.
- Burkett VR, Draugelis-Dale RO, Williams HM, Schoenholtz SH. 2005. Effects of flooding regime and seedling treatment on early survival and growth of Nattall oak. Restoration Ecology 13:471–479.
- Chamrad AD, Box TW. 1968. Food habits of white-tailed deer in South Texas. Journal of Range Management 21:158–164.
- Chang M, Crowley CM, Nuruddin AA. 1995. Responses of herbaceous mimosa (*Mimosa strigillosa*), a new reclamation species, to cyclic moisture stress. Resources, Conservation and Recycling 13:155–165.
- Chang M, Nuruddin AA, Crowley CM, MacPeak MD. 1997. Evapotranspiration of herbaceous mimosa (*Mimosa strigillosa*), a new drought-resistant species in the southeastern United States. Resources, Conservation and Recycling 21:175–184.
- Correll DS, Correll JB. 1941. A collection of plants from Louisiana. American Midland Naturalist 26:30–64.
- DeHaan LR, Weisberg S, Tilman D, Fornara D. 2009. Agricultural and biofuel implications of a species diversity experiment with native perennial grassland plants. Agriculture, Ecosystems and Environment 137:33–38.

- Diggs GM Jr, Lipscomb BL, O'Kennon R. 1999. Shinners and Mahler's illustrated flora of North-Central Texas. Fort Worth (TX): Botanical Research Institute of Texas.
- Dittus D, Muir JP. 2010. Scarification of native Texas legume seeds. Native Plants Journal 11:5–10.
- Falk AD, Smith FS, Lloyd-Reilley J, Maher SD. 2012. Notice of release of Balli Germplasm prostate bundleflower. URL: https://www.ckwri .tamuk.edu/sites/default/files/releasenotice_balligermplasm_ stpmc.pdf (accessed 2017). Kingsville (TX): Texas A&M University-Kingsville.
- Gustafson DJ, Gibson DJ, Nickrent DL. 2004. Conservation genetics of two co-dominant grass species in an endangered grassland ecosystem. Journal of Applied Ecology 41:389–397.
- Hardegree SP, Jones TA, Roundy BA, Shaw NL, Monaco TA. 2016. Assessment of range planting as a conservation practice. Rangeland Ecology and Management 69:237–247.
- Howard PH. 2015. Intellectual property and consolidation in the seed industry. Crop Science 55:2489–2495.
- Ibrahim MA, Mannetje L. 1998. Compatibility, persistence and productivity of grass-legume mixtures in the humid tropics of Costa Rica. 1. Dry matter yield, nitrogen yield and botanical composition. Tropical Grasslands 32:96–104.
- [ITIS] Integrated Taxonomic Information System. 2018. Online database. URL: http://www.itis.gov (accessed 10 Oct 2018). Washington (DC): National Museum of Natural History.
- Jackson RD, Paine LK, Woodis JE. 2010. Persistence of native C4 grasses under high-intensity, short-duration summer bison grazing in the eastern tallgrass prairie. Restoration Ecology 18:65–73.
- Jin L, Wang Y, Iwaasa AD, Xu Z, Schellenberg MP, Zhang YG, Liu XL, McAllister TA. 2012. Effect of condensed tannins on ruminal degradability of purple prairie clover (*Dalea purpurea* Vent.) harvested at two growth stages. Animal Feed Science and Technology 176:1–4.
- Johnson MB. 2006. Legumes of the Texas Rio Grande region. Aridus 18:1–6.
- Jones TA, Young SA. 2005. Native seeds in commerce. Native Plants Journal 6:286–293.
- Kupzow AJ. 1980. Theoretical basis of plant domestication. Theoretical and Applied Genetics 57:65–74.
- Lindgren DT, Schaaf DM. 2003. *Dalea purpurea* 'Stephanie.' HortScience 38:311–312.
- Lloyd-Reilley J, Maher S. 2013. Plant guide for prostrate bundleflower (*Desmanthus virgatus* var. *depressus*). Kingsville (TX): USDA Natural Resources Conservation Service, E. "Kika" de la Garza Plant Materials Center.
- Muir JP, Bow JR. 2008. Defoliation of panicled tick-clover, Tweedy's tickclover and tall bush-clover: I. Winter survival and yields of herbage and seed. Agronomy Journal 100:1631–1634.
- Muir JP, Pitman WD. 2004. Establishment of *Desmanthus* spp. in existing grass stands. Native Plants Journal 5:5–13.
- Muir JP, Reed RR, Malinowski D. 2005a. Impact of defoliation on herbage and seed production of *Strophostyles helvula* and *S. leiosperma*. Native Plants Journal 6:123–130.
- Muir JP, Taylor J, Interrante SM. 2005b. Herbage and seed from Texan native perennial herbaceous legumes. Rangeland Ecology and Management 58:643–651.
- Muir JP, Bow JR, Rodriguez W, Patterson JM. 2008. Defoliation of panicled tick-clover, Tweedy's tick-clover and tall bush-clover: II. Herbage nutritive value and condensed tannin concentrations. Agronomy Journal 100:1635–1639.
- Muir JP, Bow JR, Boggs L. 2009. Response of two perennial herbaceous Texas legumes to shade. Native Plants Journal 10:252–261.

- Muir JP, Dubeux JCB Jr, Foster JL, Pitman WD. 2014. The future of warmseason, tropical, and sub-tropical forage legumes in sustainable pastures and rangelands. African Journal of Range and Forage Science 31:187–198.
- Muncrief JB, Heizer RB. 1985. Registration of 'Sabine' Illinois bundleflower. Crop Science 25:1124.
- Noah RL, Muir JP, Wittie RD, Kattes DH, Pitman WD, Rea GL, Brakie MR. 2012a. Prairie acacia, panicled tick-clover, and herbaceous mimosa herbage, nitrogen and seed yields, nutritive value, and regional adaptation. Agronomy Journal 104:265–270.
- Noah RL, Muir JP, Brady JA, Wittie RD, Kattes DH, Pitman WD, Rea GL, Brakie MR. 2012b. Genotypic and phenotypic variability in three prairie acacia accessions. Crop Science 52:951–959.
- Norcini JG, Aldrich JH. 2007. Native wildflowers: *Mimosa strigillosa* Torr.
 & A. Gray. Publication ENH-1075. University of Florida, Institute of Food and Agricultural Sciences Extension.
- Nuruddin AA, Chang M. 1999. Responses of herbaceous mimosa (*Mimosa strigillosa*), a new reclamation species, to soil pH. Resources, Conservation and Recycling 27:287–298.
- Ocumpaugh WR, Kunz D, Rahmes J, Martinez D, Grichar WJ, Hussey MA, Reilley JL, Abrameit AH, Owens KK, Reed RL, Muir JP, Bade D. 2003. *Desmanthus bicornutus:* a new summer-growing perennial shrubby legume for South Texas and Mexico. In Cassida K, editor. American Forage and Grassland Council Proceedings. p 151–155.
- Ocumpaugh WR, Grichar WJ Jr, Hussey MA, Abrameit AH, Owens KK, Reed RL, Muir JP, Bade D, Reilley JL. 2004a. Registration of 'BeeTAM-06' bundleflower. Crop Science 44:1860–1861.
- Ocumpaugh WR, Grichar WJ Jr, Hussey MA, Abrameit AH, Owens KK, Reed RL, Muir JP, Bade D, Reilley JL. 2004b. Registration of 'BeeTAM-08' bundleflower. Crop Science 44:1861–1862.
- Ocumpaugh WR, Grichar WJ Jr, Hussey MA, Abrameit AH, Owens KK, Reed RL, Muir JP, Bade D, Reilley JL. 2004c. Registration of 'BeeTAM-37' bundleflower. Crop Science 44:1862–1863.
- Ocumpaugh WR, Grichar WJ Jr, Hussey MA, Abrameit AH, Owens KK, Reed RL, Muir JP, Bade D, Reilley JL. 2004d. Registration of 'BeeTAM-57' bundleflower. Crop Science 44:1863–1864.
- Packard C, Taylor J, Muir JP. 2004. Native, perennial, warm-season, herbaceous legumes for the Cross Timbers. Forage Research in Texas, CPR-5267. College Station (TX): Texas Agricultural Experiment Station.
- Picasso VD, Brummer EC, Liebman M, Dixon PM, Wilsey BJ. 2008. Crop species diversity affects productivity and weed suppression in perennial polycultures under two management strategies. Crop Science 48:331–342.
- Pitman WD. 2009. Establishment and survival of native legumes on upland sites in Louisiana. Native Plants Journal 10:240–250.
- Rolo VD, Rivest M, Lorente J, Kattge K, Moreno G. 2016. Taxonomic and functional diversity in Mediterranean pastures: insights on the biodiversity-productivity trade-off. Journal of Applied Ecology 53:1575–1584.
- Ruthven DC III. 2006. Grazing effects on forb diversity and abundance in a honey mesquite parkland. Journal of Arid Environments 68:668–677.
- Sanderson MA. 2010. Stability of production and plant species diversity in managed grasslands: a retrospective study. Basic and Applied Ecology 11:216–224.
- Sanderson MA, Skinner RH, Barker DJ, Edwards GR, Tracy BF, Wedin DA. 2004. Plant species diversity and management of temperate forage and grazing land ecosystems. Crop Science 44:1132–1144.
- Sanderson MA, Goslee SC, Soder KJ, Skinner RH, Tracy BF, Deak A. 2007. Plant species diversity, ecosystem function and pasture 237

management—a perspective. Canadian Journal of Plant Science 87:479-487.

- Schweitzer SH, Wester DB, Bryant FC. 1993. Potential forage species for deer in the southern mixed prairie. Journal of Range Management 46:70–75.
- Sheaffer CC, Wyse DL, Ehlke NJ. 2009. Palatability and nutritive value of native legumes. Native Plants Journal 10:224–231.
- Sheffield WJ. 1983. Food habits of Nilgai antelope in Texas. Journal of Range Management 36:316–322.
- Smith FS, Lloyd-Reilley J, Ocumpaugh WR. 2010. South Texas Natives: a collaborative regional effort to meet restoration needs in South Texas. Native Plants Journal 11:253–268.
- TAES. 1984. Sabine Illinois bundleflower. Publication no. L-2124. College Station (TX): Texas Agricultural Experiment Station.
- TAES. 1986. Comanche partridge pea. Publication no. L-2221. College Station (TX): Texas Agricultural Experiment Station.
- Thomas RD, Allen CM. 1998. Atlas of the vascular flora of Louisiana. Vol. III, Dicotyledons. Baton Rouge (LA): Louisiana Department of Wildlife and Fisheries, Natural Heritage Program.
- Tilman D, Reich PB, Knops JMH. 2006a. Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature 441:629–632.
- Tilman D, Hill J, Lehman C. 2006b. Carbon-negative biofuels from lowinput high-diversity grassland biomass. Science 8:1598–1600.
- TxDOT. 2016. Regional seed list. Austin (TX): Texas Department of Transportation. URL: http://www.txdot.gov/inside-txdot/division/ maintenance/wildflower-program/regional-list.html (accessed 2017).
- USDA NRCS. 2003. Cuero Germplasm: purple prairie clover, *Dalea purpurea* (Vent.): a conservation plant release by USDA NRCS James E. "Bud" Smith Plant Materials Center, Knox City, TX. URL: http://www. nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/ txpmcrb11368.pdf (accessed 2017).
- USDA NRCS. 2006. Littleleaf leadtree plant guide. Knox City (TX): United States Department of Agriculture, Natural Resources Conservation Service, Plant Materials Center.
- USDA NRCS. 2008. Notice of release of Plains Germplasm prairie acacia selected class of natural germplasm. Knox City (TX): United States Department of Agriculture, Natural Resources Conservation Service, James E. "Bud" Smith Plant Materials Center.
- USDA NRCS. 2011a. Hondo Germplasm velvet bundleflower. Knox City (TX): United States Department of Agriculture, Natural Resources Conservation Service, Plant Materials Center.
- USDA NRCS. 2011b. 'Kanoka' roundhead lespedeza. Manhattan (KS): United States Department of Agriculture, Natural Resources Conservation Service, Plant Materials Center.
- USDA NRCS. 2012a. Rio Grande Germplasm prairie acacia Acacia angustissima (Mill.) Kuntze var. hirta (Nutt.) B.L. Rob. URL: https:// www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/ stpmcrb11363.pdf (accessed 2017). Kingsville (TX): Natural Resources Conservation Service, E. "Kika" de la Garza Plant Materials Center.
- USDA NRCS. 2012b. Crockett Germplasm herbaceous mimosa. URL: https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/ publications/etpmcrb10847.pdf (accessed 2017). Nacogdoches (TX): United States Department of Agriculture, Natural Resources Conservation Service, East Texas Plant Materials Center.
- USDA NRCS. 2013. Release brochure for Balli Germplasm prostrate bundleflower (*Desmanthus virgatus* (L.) Willd. var. depressus

(Willd.) B.L. Turner). URL: http://www.nrcs.usda.gov/Internet/ FSE_PLANTMATERIALS/publications/stpmcrb11965.pdf (accessed 2017). Kingsville (TX): USDA Natural Resources Conservation Service, E. "Kika" de la Garza Plant Materials Center.

- [USDA NRCS] USDA Natural Resources Conservation Service. 2018. The PLANTS database. URL: http://plants.usda.gov (accessed 2017). Greensboro (NC): National Plant Data Team.
- Vines RA. 1960. Trees, shrubs and woody vines of the Southwest: a guide for the states of Arkansas, Louisiana, New Mexico, Oklahoma and Texas. Austin (TX): University of Texas Press.
- Vogel KP. 2000. Improving warm-season forage grasses using selection, breeding and biotechnology. In Moore KJ, Anderson BE, editors. Native warm-season grasses: research trends and issues. CSSA Special Publication Number 30. Madison (WI): Crop Science Society of America.
- Walden E, Lindborg R. 2016. Long term positive effect of grassland restoration on plant diversity: success or not? Plos One. May 19, p 1–16.

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