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Forage Potential of Summer Annual Grain Legumes in the Southern Great Plains

Gurjinder S. Baath,* Brian K. Northup, Alexandre C. Rocateli, Prasanna H. Gowda, and James P. S. Neel

ABSTRACT

Winter wheat (*Triticum aestivum* L.) and perennial warm-season grasses are the primary forage resources for grazing yearling stocker cattle (*Bos taurus*) in the US Southern Great Plains (SGP). However, low nutritive value of perennial grasses during mid to late summer limits high rates of growth by stocker cattle. In response, there has been a continued search for plant materials with the potential to provide forage high in crude protein (CP) and digestibility during August through September. A broad range of under-utilized legume species that are grown as grain crops in Africa, India, and South and Central America may have some capacity to serve as high quality pasture or harvested forage in the SGP. However, any crop selection must account for limitations related to unpredictable summer rainfall amounts and patterns, and the frequent occurrence of prolonged drought. Further, any selection should not create water deficits for following winter wheat, the primary forage and grain crop in the region. This article summarizes a small subset of the broad range of underutilized grain legumes (pulses) which exist worldwide and soybean [*Glycine max* (L.) Merr.] that may have capacity to serve as high quality forage for late-summer grazing. Bringing these crops into forage–stocker production systems could improve the overall system effectiveness, in addition to providing other ecosystem services (e.g., ground cover, grain crops).

Core Ideas

- Forage quality gap during mid through late summer affects stocker cattle production.
- A broad range of under-utilized grain legumes may serve as high-quality forages.
- Adoption of such crops could enhance sustainability of stocker-based grazing systems.

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THE UNITED States ranks first among the beef (*Bos taurus*) producing countries and accounted for approximately 18.2% of global production of beef in 2013 (FAO, 2017). Although there has been a decline in per capita beef consumption within the United States (from 33.8 kg in 1985 to 25.3 kg in 2016), total consumption (about 11.6 billion kg) has continually increased due to population growth (Kannan et al., 2017). Cattle production accounted for approximately \$60 billion in total agricultural sales and was the largest among US agricultural commodities, followed by \$49 billion from maize (*Zea mays* L.) sales in 2015 (USDA-NASS, 2016). The United States exported about \$6.3 billion in beef products to Japan, South Korea, Mexico, Canada, Hong Kong, and other countries in 2015 (USDA-ERS, 2017a).

Agriculture in the Southern Great Plains (SGP) is equally important to global, national, and regional food security, particularly the beef production system that developed during the late 20th century. Annually, millions of weaned calves from cow-calf operations throughout the United States are sold through local markets (Peel, 2003). Most of these animals are eventually feedlot finished in the SGP and processed at co-located slaughter and packer facilities (Fig. 1). However, there is insufficient feedlot space to accommodate all these animals simultaneously, so large numbers spend time grazing pasture in the SGP as stocker cattle, generating low-cost gain until space becomes available (Peel, 2003). Texas, Kansas, and Oklahoma represent the majority of the SGP region and are among the top five beef producing states (Fig. 1), which further outlines the importance of the region to beef production.

The SGP is comprised of diverse land types including native range, introduced perennial grasses, dryland cropping, and irrigated areas. It spreads from the front range of the Rocky Mountains in Colorado and New Mexico, eastward through Oklahoma and southern Kansas (Fig. 1). The periphery swings across northwest Texas to the southern limit of New Mexico through the Texas Panhandle and adjoining areas of west Texas and eastern New Mexico. Elevation in the region ranges from 1500 to 1800 m at the western edge to <600 m on the eastern and southern edges (Savage and Costello, 1948). The amount and timing of precipitation received annually in the SGP varies

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; IVDDM, in vitro digestible dry matter; NDF, neutral detergent fiber; SGP, Southern Great Plains.

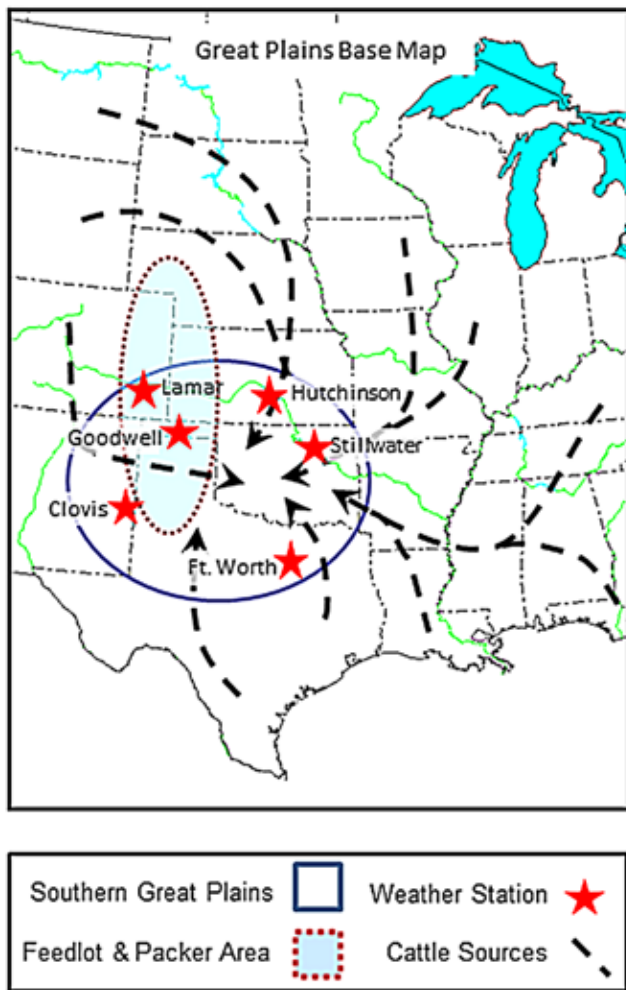


Fig. 1. Location of the southern Great Plains (SGP), sources of cattle that graze in the region in route to feedlots, and the area with large concentration of feedlots and co-located packers.

throughout the region, ranging from 395 to 449 mm in the western areas to 755 to 890 mm along the eastern fringe (Fig. 1 and 2). About half of the total annual rainfall occurs during late-spring through summer (May–September). However, the region frequently encounters prolonged periods of drought, where amount and occurrence of rainfall during this period is erratic on a monthly basis (Schneider and Garbrecht, 2003; Rao and Northup, 2011a; Patrignani et al., 2014). Maximum air temperatures are relatively uniform with low levels of variability (29.5–33°C), particularly during June through August (Fig. 3). Minimum air temperatures are more variable (14–21°C) during summer. The level of variability in precipitation and temperature within the SGP presents a challenge for defining new crops with the potential to function on a region-wide basis.

The dominant elements of forage systems that support weight gain by yearling stocker cattle in the SGP utilize annual winter wheat (*Triticum aestivum* L.) and perennial (native prairie or introduced) warm-season grasses (Phillips and Coleman, 1995; Redmon et al., 1995; Peel, 2003). These systems (Fig. 4) have been effective for grazing yearling stocker cattle but with shortcomings related to limited availability of high-quality forage in May and from August through October (Phillips and Coleman, 1995; Coleman and Forbes, 1998; Northup et al., 2007). Combinations of forages arrayed in larger systems are required

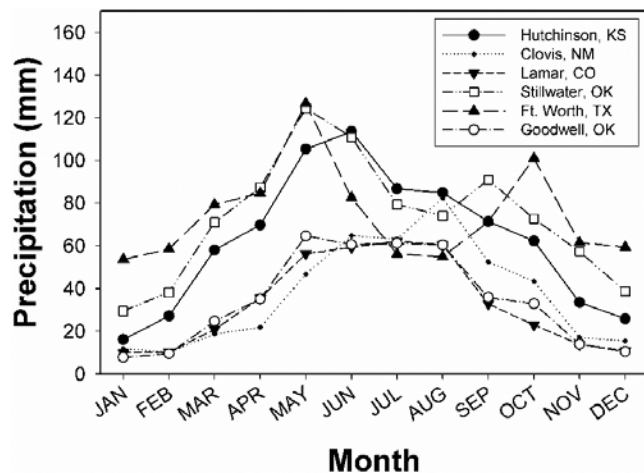


Fig. 2. Long-term (1966–2016) average monthly precipitation for six locations within the US Southern Great Plains (SGP).

to lengthen the time that high-quality forage is available and limit shortcomings during the production cycle (Northup et al., 2007; Phillips et al., 2009; Patrignani et al., 2014).

Winter wheat is also the primary agricultural crop planted in the SGP region, with more than 2.6 million ha planted annually in Oklahoma (Hossain et al., 2004). It serves producers as a drought avoidance crop, by taking advantage of soil moisture that accumulates during summer fallow (June–August) and September rainfall, and matures early enough to avoid the hot and dry conditions that occur during summer. Summer fallow serves as a technique to minimize risk of crop failure. Aiken et al. (2013) reported 18 and 31% reductions in wheat forage and grain yields, respectively, due to 132 mm less soil water in wheat–soybean [*Glycine max* (L.) Merr.] rotations compared with wheat–fallow rotations in western Kansas. However, there are numerous sustainability issues for wheat–fallow rotations, including poor precipitation use efficiency (Farahani et al., 1998), potentially greater soil erosion, and decreased soil organic C and N, depending on tillage system (Kelley and Sweeney, 2010). No-till systems can help alleviate such problems, but there has been limited adoption by wheat producers in the region. For example, a survey in Oklahoma (Hossain et al., 2004) reported roughly 89% of producers who use continuous winter wheat–summer fallow systems apply conventional tillage to 56% of the total area planted to wheat, while 36 and 8% of cropland is managed by reduced and no-till systems, respectively (Conservation Technology Information Center, 2004).

Wheat is a dynamic and flexible crop capable of producing multiple commodities within one growing season, based on its competing values as grain, hay, and livestock gain (Peel, 2003; Decker et al., 2009; Edwards et al., 2011). Wheat serves as the primary source of high-quality forage for stocker cattle from late fall through early spring (Fig. 4). According to a survey in Oklahoma (Hossain et al., 2004), the intended use of winter wheat was 20% for pasture only, 49% for a dual-purpose role (winter grazing and spring grain), and 31% for production of grain only. Wheat grown for grain is planted during late September through early October to avoid the potential occurrence of dry growing conditions in early September (Lyon et al., 2007). Alternatively, dual-purpose wheat (graze–grain) is generally planted in early to mid-September and grazed from mid-November until the occurrence of first

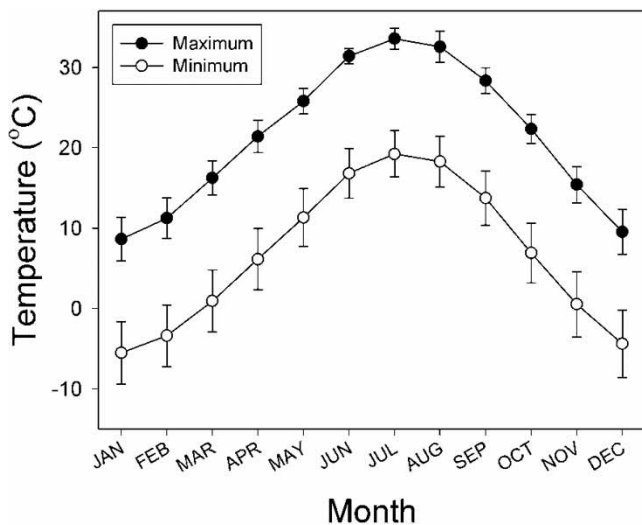


Fig. 3. Long-term (1966–2016) average monthly maximum and minimum air temperatures of six locations within the US Southern Great Plains (SGP). Error bars indicate standard deviation.

hollow stem (early March) stage of growth (Fieser et al., 2006; Edwards et al., 2011). Wheat grown for grazed pasture (graze-out) is planted in early September, to maximize forage production during November through April (Fig. 4).

Pasture of perennial warm-season grasses including bermudagrass [*Cynodon dactylon* (L.) Pers.], Old World bluestems (*Bothriochloa* spp.), and native prairie have been the traditional forages for summer grazing, though mostly in support of cow–calf operations (Fig. 4; Phillips and Coleman, 1995; Coleman and Forbes, 1998; Rao et al., 2002). In contrast to cow–calf pairs, production of stocker cattle requires a large amount of high-quality forage to fulfill both growth and maintenance requirements of animals (Phillips and Coleman, 1995; Neel et al., 2007). An important issue for grazing stocker cattle is the decline in forage quality of these perennial grasses with maturation as the growing season advances (Coleman and Forbes, 1998). This decline becomes a limiting factor for stocker production without protein supplementation (Phillips and Coleman, 1995; NRC, 1996). Given the growth patterns of winter wheat and the more typical perennial warm-season grasses, there is no single forage crop capable of providing nutritious biomass for year-round grazing. A possible solution is to find nutritious forages that can fill the void during mid-summer and enhance sustainability of forage-stocker systems. However, any such potential crops must also perform well within the widely adopted systems used in production of the primary crop of the SGP (winter wheat) without generating deficits in soil resources that are important to establishment and growth by winter wheat (Rao and Northup, 2009b).

Work undertaken over the last two decades in the SGP has searched for annual grain legumes (pulses) with potential to serve as either forages or green manures (Rao et al., 2005; Rao and Northup, 2009a, 2011b; Butler and Muir, 2012; Northup and Rao, 2015, 2016). Some of the tested pulses showed potential to provide high-N biomass (Rao and Northup, 2009a, 2012, 2013; Northup and Rao, 2015). However, the presence of large diameter, low quality stems limits the value of many pulses for grazing (Rao and Northup, 2013). Further, the biomass of many species contains secondary plant compounds, especially tannins and other polyphenolics (Price et al., 1980; Kumar and Singh, 1984; Ajayi et

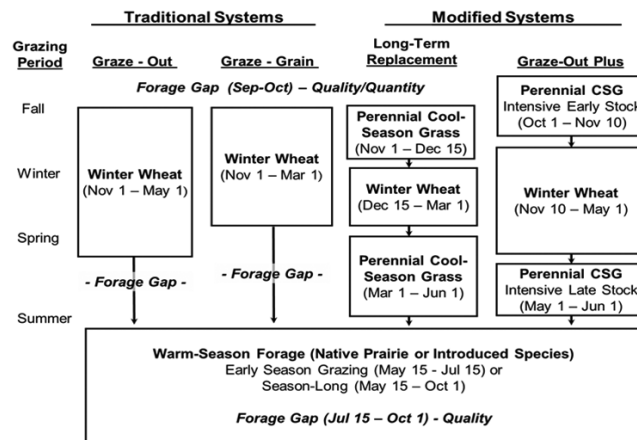


Fig. 4. Gaps in available traditional winter wheat–summer forage systems in the SGP.

al., 2009). Both factors restricted grazing to short time periods of the lifecycle of the tested pulses (Rao and Northup, 2012). Such issues and limitations for the tested legumes indicate there is still a need for research to identify alternate species of pulses that may serve as sources of high N biomass for agroecosystems in the SGP.

Worldwide, roughly 7000 plant species are cultivated to feed humans. However, just 20 species meet 90% of the total food requirements for humans (Chivenge et al., 2015). The remaining species are underutilized or their use is restricted to limited areas such as sub-Saharan Africa. Such a large pool means there is a diverse range of underutilized crops that may have the capacity to provide grazing or hay for cattle in the SGP. Identifying well-adapted legume species from such a broad base of crops for use as forage in stocker production systems of the SGP could enhance the sustainability of stocker-based grazing systems, or increase agro-ecosystem diversity by providing new cover or grain crops.

Selection of the proper crop for summer periods will be critical due to the agro-climatic conditions in the SGP. Most crops tend to function better in systems with greater amounts of available water due to reduced competition for this limited resource (Snapp et al., 2005). However, competition for moisture between summer crops and subsequent winter wheat in the SGP needs addressing, as irrigation is not an option for most producers in the region. The performance of dryland winter wheat, particularly during the period of germination and early fall growth, relies on moisture stored in the soil profile (Rao and Northup, 2011b). Therefore, the emphasis should be on identifying crops that are productive in response to the variable climate of the SGP, and have limited effects on soil moisture to minimize carryover effects on subsequent wheat crops. This review discusses soybean, the most commonly used legume in the SGP, and some species of pulses from arid and semiarid regions that might fit the forage–livestock production systems of the SGP as summer forage.

SOYBEAN

Soybean, an oilseed legume species, originated and was domesticated in south China (Guo et al., 2010). It is widely grown across many parts of the world. Soybean has an erect growth habit and can grow to a height of 1.3 m (Lee et al., 1996). Cultivated soybean plants have trifoliate leaves with oval to lanceolate leaflets and purple, pink, or bluish papilionaceous flowers. It has a well-developed taproot system, which can extend

to a depth of 1.5 m (Ordóñez et al., 2018). The United States is currently the largest producer (35% of world production) of soybean, followed by Brazil (29%) and Argentina (17.5%) (FAO, 2017; Ciampitti and Salvagiotti, 2018). Within the United States, 31 states produce soybean with Illinois, Iowa, Minnesota, and Indiana as the top four producers (USDA-NASS, 2017).

Soybean is largely grown for grain, which has multiple uses. Raw soybean contains 360 g kg⁻¹ protein, 300 g kg⁻¹ carbohydrates, 200 g kg⁻¹ fat, and many essential vitamins and minerals (USDA-ARS, 2016) and serves as an important component in the diets of vegetarians and vegans across the world. The consumption of soybean foods has continuously increased in the last few decades due to its health benefits, including prevention of cancer, obesity, and diabetes, lowering of cholesterol, and protection against kidney and bowel disease (Friedman and Brandon, 2001). Further, soybean oil is currently a leading feedstock for biodiesel production in the United States and considered as an effective and economical component in products such as paints, resins, rubber, polyurethane, and coatings.

Within soybean, variation in the daylength, which initiates the physiological transition from vegetative to reproductive stages, results in cultivars being classified into different maturity groups (Zhang et al., 2017). It generally takes 100 to 120 d to reach maturity with mid-late maturity group cultivars in the SGP (Rao and Northup, 2009a; Wagle et al., 2017). The late maturity group cultivars produce greater forage biomass during September–October than other cultivars in the SGP (Rao et al., 2005). Soybean requires a temperature range of 25 to 30°C for an optimum growth, and its reproduction is affected at temperatures above 35°C (Salem et al., 2007; Setiyono et al., 2007). The total water requirement of soybean ranges from 420 to 540 mm in the Midwest region of United States (Payero et al., 2005; Suyker and Verma, 2009).

Soybean was primarily grown as a forage crop after its introduction into the United States in the mid-19th century (Probst and Judd, 1973). However, grain land area surpassed forage land area by 1941 due to the demand for its oil and meal. In the last two decades, there has been renewed interest by researchers in evaluating soybean as a forage crop in the United States (Sheaffer et al., 2001; Rao and Northup, 2008; Nielsen, 2011; Beck et al., 2017). In the SGP, forage yields of soybean ranged between 1.1 and 5.4 Mg ha⁻¹ with 150 to 190 g kg⁻¹ CP and 740 to 790 g kg⁻¹ in vitro digestible dry matter (IVDDM; Rao et al., 2005; MacKown et al., 2007; Rao and Northup, 2009a; Northup and Rao, 2015). It was found to produce insufficient biomass (<1.5 Mg ha⁻¹) in the years receiving low precipitation (<50 mm) during early summer (Rao and Northup, 2009a; Foster et al., 2009; Northup and Rao, 2015), which would cause limitations on forage intake by yearling cattle (Coleman et al., 2010). Double-cropping winter wheat and soybean is an important practice in many regions across the United States (Knott et al., 2018). However, when the approach was investigated by MacKown et al. (2007) and Northup and Rao (2015) in the SGP, it was found to be ineffective. Given the variability associated with spring and summer rainfall patterns in the SGP, productivity of double-cropped soybean as forage was reported as marginal (1.17 Mg ha⁻¹), and the function of soybean as a green manure failed to offer any N benefit to winter wheat or increase

C and N concentrations after 3 to 4 yr (MacKown et al., 2007; Northup and Rao, 2015).

TEPARY BEAN

Tepary bean [*Phaseolus acutifolius* (A.) Gray] is an annual legume native to northwestern Mexico and the southwestern United States. Cultivated tepary bean plants have either bush or semi-vine type growth forms, with pointed trifoliolate leaves, short and slightly hairy green pods, and deep tap root systems (Stephens, 1994). Tepary bean was once a vital part of the “Native American diet” in its home range and was specially honored at the 1912 International Dry Bean Congress for its flavor and reliable yields in rainfed cropping systems (Bhardwaj et al., 2002). However, the spread and development of tepary bean stayed limited to specific forms of dryland farming due to irrigation developments and restricted marketing in the southwestern United States (Porch et al., 2013). It has been receiving increased attention from researchers for adaptability to dry conditions and as a genetic donor to improve drought tolerance in common bean (*Phaseolus vulgaris* L.) (Pratt, 1983; Singh and Munoz, 1999; Rainey and Griffiths, 2005).

On the African continent, tepary bean has been recognized as an important food crop to combat malnutrition and enhance income and livelihoods of resource-limited farmers in many countries, including Kenya and Zimbabwe (Jiri and Mafongoya, 2016). Small farmers in Botswana grow tepary bean for food and utilize the haulms (stems) as feed for animals (Molosiwa et al., 2014).

One of the nutritional features of all bean plants is the presence of large amounts of protein and fiber in their seed. Grain of tepary bean has high protein (240 g kg⁻¹) and iron (0.1 g kg⁻¹) concentrations (Bhardwaj and Hamama, 2004). The bean contains 18 g kg⁻¹ oil with 330 g kg⁻¹ saturated and 670 g kg⁻¹ unsaturated fatty acids. Among the unsaturated fatty acids, 240 g kg⁻¹ are monounsaturated, and 420 g kg⁻¹ are polyunsaturated (Bhardwaj and Hamama, 2005). Apart from its high nutritional value, tepary bean has been reported to have some medicinal value. They possess unique characteristics to combat diabetes and treat the development of cancer (Garcia-Gasca et al., 2002).

Tepary bean is a suitable crop for hot and dry environments. It requires a temperature range of 25 to 35°C for optimum germination and has a minimum requirement of 8°C for its vegetative growth (Scully and Waines, 1987, 1988). Miklas et al. (1994) reported a grain yield of 770 to 1640 kg ha⁻¹ across an array of environments in Central America with a precipitation range of 164 to 396 mm during a growing season and average minimum and maximum temperature ranges of 16.1 to 22.8°C and 29.3 to 32.5°C, respectively. In addition, tepary bean seems to improve the soil fertility through biological N fixation (Shisanya, 2002). Bhardwaj et al. (2002) grew tepary bean successfully as a short-duration summer crop in rotation with winter wheat in Virginia, which has more humidity and precipitation than the SGP. Markhart (1985) reported that tepary bean tolerates drought better than common bean by closing its stomata at a much higher water potential when exposed to water stress. It is found to be highly tolerant of heat, salinity, many diseases, and insects (Miklas et al., 1994; Miklas and Santiago, 1996; Pratt et al., 1990).

Tepary bean has exhibited great potential for forage production, though published literature is limited. Bhardwaj (2013) reported fresh and dry yields of 22.2 and 4.4 Mg ha⁻¹, respectively, at 59 d after planting on a sandy loam soil in eastern Virginia. Forage quality of tepary bean reported in this study appears to be comparable with alfalfa and soybean forage in terms of CP; however, it had greater fiber concentrations (Table 1).

Tepary bean may fit well within the management systems applied to winter wheat in the SGP due to its drought tolerance and relatively short life cycle of around 60 to 75 d (Tinsley et al., 1985). The limited amount of information also indicated tepary bean might provide much needed nutritious forage during the late-summer period (Bhardwaj, 2013). Grazing or one cutting for hay with subsequent plow down would be a possible method of management. Further, lines that have semi-vine growth forms may also have value as cover crops. However, due to the lack of field studies, more research is required to evaluate its feasibility as a forage crop in the SGP.

MOTHBEAN

Mothbean [*Vigna aconitifolia* (Jacq.) Marechal] is an annual summer legume, cultivated mainly in the semiarid and arid regions of India due to its high drought and heat tolerance. Mothbean is a short-duration crop with a 60- to 75-d lifespan (Kumar and Rodge, 2012). Optimum production can be achieved within a temperature range of 24 to 32°C, but mothbean can tolerate daytime temperatures up to 45°C (Vijendra et al., 2016). Water requirements of mothbean during a growing season are quite low, ranging between 190 and 260 mm in its native regions (Rao and Poonia, 2011). Singh et al. (2000) estimated an evapotranspiration rate of 1.8 to 2.2 mm d⁻¹ and 4.8 mm d⁻¹, respectively, during early vegetative and reproductive growth stages. Therefore, it has the potential to perform well in environments with low and erratic amounts of rainfall (Narain et al., 2001), which is a regular feature of summer precipitation in the SGP. The wide adaptability of mothbean enables it to grow on sand dunes or other marginal lands with slight salinity and a wide pH (3.5–10) range (Manga et al., 2015; Vijendra et al., 2016).

Mothbean serves as a multipurpose crop in its native range as a source of food, forage, and green manure (Manga et al., 2015). Mothbean seeds are rich in protein (230 g kg⁻¹) and contain some essential amino acids, minerals, carbohydrates, fiber, and vitamins (Siddhuraju et al., 1994; USDA-ARS, 2016). Although it is mainly grown in arid or desert regions of India, it seems to be adaptable to a broad range of climatic conditions. Research over 100 yr ago (Conner, 1908) reported a yield (fresh wt.) of 4.4 Mg ha⁻¹ in northwestern Texas when planted at a 90-cm row spacing; no seed set was recorded at that location. Kennedy and Madson (1925) reported yields (fresh wt.) of 45 and 60 Mg ha⁻¹, respectively, when planted at a 90-cm row spacing under irrigated and dryland conditions near Fresno, CA. The given explanation for greater yield in dryland conditions was good condition of the seed bed at planting, which resulted in a better stand than under irrigated conditions. They also reported an average seed yield of 198 kg ha⁻¹ from a mothbean study conducted near Davis, CA. Bhardwaj and Hamama (2016) reported seed yields of mothbean varied from 55 to 468 kg ha⁻¹ in a test of 54 accessions in the eastern United States. In central Oklahoma, a preliminary study involving 10 mothbean

Table 1. Comparison of forage quality of tepary bean with alfalfa hay and forage soybean.

Forage	Forage quality traits			Citation
	CP	ADF	NDF	
	g kg ⁻¹			
Tepary bean	214	375	411	Bhardwaj, 2013
Alfalfa hay	200	303	365	LaCasha et al., 1999
Forage soybean	192	293	407	Hintz et al., 1992

lines reported a dry forage yield of 7.3 to 18.1 Mg ha⁻¹ and grain yield of 0.1 to 1.0 Mg ha⁻¹ on harvesting mothbean at 100 d after planting (Baath et al., 2018). The same study reported that mothbean forage possessed 110 to 150 g kg⁻¹ CP, 320 to 420 g kg⁻¹ neutral detergent fiber (NDF), 210 to 300 g kg⁻¹ acid detergent fiber (ADF), and 730 to 840 g kg⁻¹ in vitro true digestibility at maturity.

Mothbean could be used to increase the supply and quality of forage in semiarid and arid regions (National Research Council, 1979). Individual plants have a vining and semi-trailing growth habit, which have the potential to cover large areas. As such, this low-growing legume has the potential to cover the soil surface to protect soil moisture, reduce soil temperatures, and decrease soil erosion (Bhardwaj and Hamama, 2016). Since it is a legume, mothbean can also improve soil fertility through N fixation (Vir and Singh, 2015).

Research on the use of mothbean as forage was initiated during the early 20th century and showed promising results in dry US environments (Conner, 1908; Kennedy and Madson, 1925). However, the crop was neglected afterward for unknown reasons. Based on its food and forage potentials, soil covering ability, and short life cycle, mothbean appears to be a candidate for improving not only livestock production systems when grown as a summer crop in rotation with winter wheat but also for increasing agro-ecosystem diversity in the SGP.

COWPEA

Cowpea [*Vigna unguiculata* (L.) Walp.] is an important herbaceous, warm-season legume that originated and was domesticated in Africa. Cowpea varieties exhibit different growing habits including tall and vine-like, short and bushy, or prostrate. Cowpea plants have leaves with three broad leaflets, white inflorescences, and curved pods (Sheahan, 2012). Most cowpea types possess an indeterminate stem and branch apices (Timko et al., 2007). It has a deep tap root, which has been measured at a depth of 2.9 m at flowering (Babalola, 1980). It is a valuable food legume and livestock feed in the semiarid tropics, including regions of Asia, southern Europe, Africa, Central and South America, and the southern United States (Timko and Singh, 2008).

Cowpea is a well-adapted and versatile crop, capable of good yields under high temperature and water deficits (Ehlers and Hall, 1997; Hall et al., 2002). It requires a minimum temperature of 18°C through all developmental stages (Timko and Singh, 2008; Badiane et al., 2014). Optimum growth occurs at mean daily air temperatures of 28°C (Craufurd et al., 1997). Cowpea is generally photo insensitive (Davis et al., 1991). It is drought tolerant and can produce a grain yield of about 1.1 Mg ha⁻¹, with rainfall amounts as low as 180 mm during the growing season (Hall and Patel, 1985). However, it does not withstand flooded conditions over long periods (Clark, 2007). Cavalcante Junior et al. (2016)

MUNGBEAN

reported water requirements of cowpea ranging from 240 to 310 mm under semiarid conditions in Brazil. Cowpea can fix N and has performed well in sandy (80%), low fertility soils with <0.2% organic matter and low P (Sanginga et al., 2000). Cowpea is also shade tolerant, and capable of being intercropped with tall forage crops including sorghum [*Sorghum bicolor* (L.) Moench], maize, cotton (*Gossypium hirsutum* L.), and sugarcane (*Saccharum officinarum* L.; Singh et al., 2003).

Cowpea is an absolute multifunctional crop, since it serves as a highly nutritious food, a forage, and a green manure or cover crop. Cowpea grain has served as a dietary source of protein in areas with low-protein cereal and tuber-based diets. Cowpea seed contains 240 g kg⁻¹ protein, 600 g kg⁻¹ carbohydrates, 110 g kg⁻¹ fiber, 13 g kg⁻¹ fat, and considerable amounts of vitamins and minerals (USDA-ARS, 2016). It can also be employed as livestock feed (Singh et al., 2006).

Cowpea has the capacity to serve as fodder due to its high biomass yield and forage value. The common name cowpea even originated because of its use as hay for cattle in the United States and other parts of the world (Timko et al., 2007). Cowpea hay plays a critical role in feeding livestock during the dry season in West Africa (Tarawali et al., 1997). In a study on nutritive value of forage conducted in Iran (Dahmardeh et al., 2009), cowpea fodder was shown to have 156 to 196 g kg⁻¹ CP, 497 to 545 g kg⁻¹ NDF, and 293 to 322 g kg⁻¹ ADF. It has a low risk of causing bloat in cattle, although bloat may occur on introducing hungry stock onto the crop (Mullen and Watson, 1999).

Generally, the short duration varieties (about 65–70 d) are grown for grain, whereas the long duration (110–130 d) varieties are used for forage. Some varieties with medium maturity rates (80–85 d) exist for a dual-purpose role. These varieties yield about 1.5 Mg ha⁻¹ grain and 2.5 Mg ha⁻¹ haulms, with a CP of 170 to 180 g kg⁻¹ and dry matter digestibility of 640 to 710 g kg⁻¹ (Singh et al., 2003). It is also an excellent cover crop candidate, being fast growing, having a long taproot, and immense vegetative spread (Sheahan, 2012). About 50 cowpea varieties are commercially grown in the United States in regions extending from the Great Lakes to Florida and from the Atlantic to Pacific coasts (Sheahan, 2012).

Cowpea is one of the few annual legumes besides soybean that has received some degree of research and use in the SGP. Forage cowpea in north-central Texas yielded 0.5 to 3.2 Mg ha⁻¹ dry matter with CP concentrations ranging from 161 to 208 g kg⁻¹ under dryland conditions; both amounts were greater than that of forage soybean (Muir, 2002). Rao and Northup (2009a) reported that cowpea had greater potential as a summer crop for forage or green cover than soybean during dry years in the SGP due to its shorter lifecycle, high N concentrations and forage digestibility. Depending on the management and seasonal circumstances, cowpea can be grazed 8 to 12 wk after planting until the leafy portion has been eaten (Mullen and Watson, 1999). Cowpea appears to be another option for producers of the SGP wishing to grow a summer crop to enhance sustainability of rain-fed forage–livestock production systems. The genetic improvements in modern cultivars (Sheahan, 2012) indicates there is need for additional research on the values of cowpea as a summer forage in the SGP.

Mungbean [*Vigna radiata* (L.) Wilczek.], also known as green gram, is an annual warm-season legume, with a highly branched and upright growth form, and trifoliate leaves. It has a well-developed taproot reaching to a depth of 1.0 m (Sangakkara et al., 2001). It is native to the northeastern Indo-Burma region, and is one of the major food legume crops of Asia (Bhardwaj and Hamama, 2016). Mungbean seeds provide high amounts of easily digestible protein for human consumption (Swaminathan et al., 2012). Mungbean grain contains 240 g kg⁻¹ protein, 15 g kg⁻¹ oil, and 50 g kg⁻¹ sugars (Bhardwaj and Hamama, 2016). Whole seeds are commonly used to grow bean sprouts for salads or used in soup mixes in the United States.

Mungbean is adaptable and has been cultivated in different parts of the world including Southeast Asia, Africa, South America, North America, and Australia. It has a short life cycle, requiring 90 to 120 frost free days to achieve maturity (Ranawake et al., 2012). Mungbean is commonly grown with daily temperatures ranging from 20 to 40°C; the minimum temperature requirement for emergence is 12°C, and the range of optimum growth is 28 to 30°C (Fyfield and Gregory, 1989; Kaur et al., 2015). The total water requirement of mungbean ranges from 440 to 520 mm under irrigated conditions of northern India (Phogat et al., 1984; Pannu and Singh, 1993). However, mungbean can be grown successfully under lower moisture, rain-fed conditions (Ranawake et al., 2012). It requires guaranteed soil moisture via pre-sowing irrigation or adequate rainfall for better germination and stand establishment (Kumar and Sharma, 2009). Allahmoradi et al. (2011) reported vegetative growth of mungbean was more susceptible to drought stress than reproductive stages. However, Thomas et al. (2004) found mungbean was capable of recovering from drought stress during early development and compensating for yield losses later in the growing season.

The planting and production strategies for mungbean are similar to soybean, so producers in the SGP would not require specialized equipment for planting and grain harvest (Bhardwaj and Hamama, 2015) or different strategies for grazing management. Mungbean plants may have potential as cattle forage due to high digestibility (825 g kg⁻¹) and N concentrations (26 g kg⁻¹) (Rao and Northup, 2009a). Twidwell et al. (1992) reported CP concentrations of 150 to 230 g kg⁻¹ in mungbean forage. Boe et al. (1991) reported forage yields of 3.75 to 7.25 Mg ha⁻¹ for cultivars of mungbean tested in the northern Great Plains. In comparison, Rao and Northup (2009a) obtained an average forage yield of about 3 Mg ha⁻¹ in central Oklahoma in response to a range of different amounts of precipitation during growing seasons. Grazing of mungbean can start 6 wk after planting and two grazing periods are obtainable (FAO, 2012). Hay harvests should occur at initiation of flowering for optimum combination of quantity and quality of biomass (Heuzé et al., 2013).

Although mungbean has been grown in Oklahoma and Texas in the past, the current level of grain production is low. Most of the US demand for mungbean is met through import, with 15.8 and 16.4 Mg of mungbean and urd bean (*Vigna mungo* L.) being imported in 2015 and 2016, respectively (USDA-ERS, 2017b). Such demand shows mungbean grain has US market value and could help increase farmer income in the SGP. This

Table 2. Characteristics of annual legumes grown in different regions of the world with potential for the summer growing season of the Southern Great Plains.

Crop	Native range	Growing conditions					Forage quality				
		Growing climate	Optimum temp. °C	Water required mm	Root depth m	Growing season days	Livestock feed	CP	IVDDM	Forage yield Mg ha ⁻¹	Grain yield
Soybean	China	Sub-humid	25–30	420–540	1.5	100–120	Hay/graze	150–190	740–790	1.1–5.2	0.3–1.5
Tepary bean	NW Mexico and SW United States	Arid	25–35	NA	NA	60–75	Hay/graze	210	n/a	4.4	0.8–1.6
Mothbean	India	Arid	24–32	190–260	NA	60–75	Hay/graze	110–150	730–840	7.1–18.1	0.1–1.0
Cowpea	Africa	Semi-arid	28	240–315	0.8–2.8	65–70	Hay/graze	160–210	640–710	0.5–3.2	1.5
Guar	Africa	Semi-arid	25–35	250	NA	90–120	Hay	160–220	610–710	2.9–4.7	1.1–1.8
Mungbean	Indo-Burma	Sub-humid	28–30	440–520	1.0	90–120	Hay/graze	150–230	825	3–7.5	1.5
Pigeon pea	India	Semi-arid	20–24	200–240	2.0	110–140	Graze/seeds as feed	121	689	3–9	1.2–5.4

value assumes the development of consumer demand (and marketing mechanisms) that exceeds its value as high quality forage for summer grazing by stocker cattle. Karamany (2006) investigated a dual-purpose approach for mungbean during summers in Egypt. They recorded 5 Mg ha⁻¹ of high quality forage (172 g kg⁻¹ CP) at harvest of mungbean as hay at 65 d after sowing. These plots were also able to produce an average of 1.5 Mg ha⁻¹ seed yield at the end of growing season. The short growing season of mungbean would result in grain harvest by late August in the SGP, which would help conserve soil moisture received in September and October for winter wheat (Rao and Northup, 2009b). Asim et al. (2006) also noted reduced weed, pathogen, and pest problems for subsequent wheat crops.

Mungbean plants are a potential crop choice to improve productivity of grazing systems, assist in soil moisture conservation, provide reliable economic benefits, and enhance soil fertility. Based on the long-term weather data of the six locations (shown in Fig. 2 and 3), mungbean seems to be a better fit for the eastern sections of the SGP due to greater water needs than other potential summer annual legume crops (Table 2).

GUAR

Guar [*Cyamopsis tetragonoloba* (L.) Taub.], also called cluster bean, is a drought tolerant, summer annual legume that is thought to have originated in Africa. It is mainly cultivated in semiarid zones of northwestern India, Sudan, and Pakistan. There has been some production and genetic development within the southern United States (Stafford, 1982; Reddy and Tammishetti, 2004). India is currently the largest producer (80% of world production) of guar in the world, followed by Pakistan (15%), and the Middle East and African (5%) countries (Gresta et al., 2013). Guar has a single upright main stem (2–3 m) with fine or basal branching stems, trifoliolate leaves, 4- to 10-cm long pods with 5 to 12 seeds per pod, and a deep taproot system enabling it to reach moisture below the surface layers of soil (Gresta et al., 2013).

Guar is a shorter-duration crop, requiring 90 to 120 d to reach maturity, which allows it to fit into different crop rotations (Rao and Northup, 2009a, 2013). However, guar is photosensitive, requiring long days for vegetative growth and short days for flowering and pod formation. Seed germination needs temperature within a range of 25 to 30°C, and can grow at air temperatures of 35°C (Singh, 2014). Guar can grow in a wide range of soils, but performs best on fertile, medium textured soils with good drainage. Guar is a drought tolerant crop, delaying growth until

moisture is available (Tripp et al., 1982). As such, guar can grow in areas receiving ≤250 mm of annual precipitation (Singla et al., 2016a). Therefore, the environmental conditions of regions where guar is grown in large quantity closely match conditions in the SGP.

Guar has great value in India due to its use to provide multiple products, including forage or feed for cattle, a nutritious vegetable (immature pods) for human consumption, a green manure for soil improvement, and a raw material for several different industries. The grain of guar is a rich source of protein, fiber, minerals (Ca, Fe, and P), and ascorbic acid (Singh, 2014). Guar seeds have numerous industrial uses due to its binding capability and viscosity of the polysaccharide galactomannan (guar gum), which is obtained from the endosperm (Singla et al., 2016a). High-grade guar gum is utilized in food industries, whereas low-grade gum is used in the textile, paper, and mining industries. Recently, the demand and price of guar gum has increased globally due to its use in oil fracking (Gresta et al., 2013). Within the fracking industry, the largest consumption of guar gum in the world is by US companies, with most of the demand being met through importation (Singh, 2014; Singla et al., 2016b). Therefore, it is primarily grown as a seed crop in the United States. Singla et al. (2016b) reported grain yields of 1.1 to 1.8 Mg ha⁻¹ for eight different varieties evaluated in Las Cruces, NM. Guar also can improve soils through its soil-binding roots and N fixation, which benefit subsequent crops (Wong and Parmar, 1997). Cotton yields were increased by 15% when grown in rotation with guar (Tripp et al., 1982).

Although guar has been cultivated mainly as a grain crop in the United States, it may also have forage potential, although information on the value of guar as either hay or grazed pasture is mixed. Guar hay was found to be palatable and digestible to livestock in India (Patnayak et al., 1979). In comparison, Rao and Northup (2013) suggested guar as potential forage for the SGP, and an annual alternative to high water-demanding legumes like alfalfa (*Medicago sativa* L.). Rao and Northup (2009a) reported 162 to 225 g kg⁻¹ CP and 606 to 712 g kg⁻¹ IVDDM for forage produced by a grain cultivar Kinman in Oklahoma. Studies in the SGP also suggested that hay may be harvested during vegetative stages of growth, as CP and digestibility were continuously reduced with increasing levels of plant maturity (Rao and Northup, 2009a, 2013). Singla et al. (2016a) reported an average biomass yield of 2.9 to 3.8 Mg ha⁻¹ near Las Cruces, NM. Rao and Northup (2013) reported a forage yield

of 4.25 to 4.75 Mg ha⁻¹ for three Indian-origin forage varieties grown in central Oklahoma.

Although the value of guar as a hay crop looks promising, there is limited information on its value as grazed pasture, and many reports are anecdotal. The surface of guar leaves is covered in fine hairs, which were thought to hinder grazing in India. However, there has been little research on the interaction between guar and grazing animals. Such information is important for defining the suitability of guar as forage or hay. Further research is also needed to ascertain more reliable forage-type cultivars, their performance and quality attributes, and best management practices for the variable environment of the SGP.

PIGEON PEA

Pigeon pea [*Cajanus cajan* (L.) Millsp.], also known as red gram, is a legume from the rainfed tropics and subtropics, which has a substantial shrub-type growth form (Singh and Oswalt, 1992). Pigeon pea originated and was domesticated in India. Plants of pigeon pea have erect, woody, pubescent stems of 1 to 4 m height, alternate trifoliolate leaves, papilionaceous (butterfly-shaped) and yellow flowers organized in racemes, and pubescent pods that form at the axils of branches. Pigeon pea has a strong taproot, which can extend to a depth over 2 m (Singh and Oswalt, 1992).

There is a wide range of genetic materials for this legume, and cultivars with a broad range of length of growing seasons exist (Mallikarjuna et al., 2011). In its native range, there are perennial cultivars that can be grown for 3 to 5 yr. However, mostly annual cultivars are preferred for seed production in tropical and subtropical regions (Singh and Oswalt, 1992; Mallikarjuna et al., 2011). Short-duration cultivars have been developed that are capable of grain production in the southern United States (Phatak et al., 1993; Yu et al., 2014), and such materials were tested in the SGP (Rao et al., 2002, 2003). Pigeon pea contributed 6% of the total worldwide production of pulse crops in 2014 (FAO, 2017). Pigeon pea reaches maturity within a range of 120 to 210 d depending on the cultivar type, location, and sowing time. Rao et al. (2003) observed short-duration (110–140 d) US varieties reached physiological maturity 118 d after planting in the SGP. Pigeon pea is a short-day plant and requires an optimum temperature between 20 and 24°C for development (McPherson et al., 1985; Carberry et al., 2001).

Pigeon pea can grow in soil types ranging from sand to heavy clay loams. The water requirements of pigeon pea in India ranged between 200 and 240 mm when grown during summer (Mahalakshmi et al., 2011). Limited accounts are available on water use by pigeon pea; however, it has remarkable drought tolerance due to its deep roots and ability to undergo osmotic adjustment in its leaves (Subbarao et al., 2000). Although pigeon pea is mainly grown under rainfed conditions, it is affected by intensity and timing of rainfall. Yu et al. (2014) in west-central Tennessee found 172% greater seed yield in a year receiving normal rainfall combined with drought during the early growing season compared with a year receiving heavy rainfall during early growing season and severe drought at flowering. Similar responses to different rainfall patterns occurred in central Oklahoma (Rao and Northup, 2009b). Pigeon pea was also noted to have higher water use efficiencies under dry conditions compared with wet growing conditions (Yu et al., 2014).

Pigeon pea has been used as a true multi-purpose crop in India and Africa, with the entire plant used to supply human and livestock feedstuffs, enhance soil fertility, and supply fuel for cooking fires (Singh and Oswalt, 1992). The raw mature seeds contain 193 g kg⁻¹ protein, 627 g kg⁻¹ carbohydrates, 64 g kg⁻¹ fiber, 20 g kg⁻¹ sugars and are a rich source of dietary minerals such as P, K, Mg, Ca, and Fe (Singh and Singh, 1992). The demand for pigeon pea seeds has increased during the last few years due to US immigration from countries where pigeon pea has been grown for grain or vegetable (immature pods).

Leaves and pods of pigeon pea are widely used as livestock forage due to high amounts of protein and palatability. Rao et al. (2003) reported average CP concentration and IVDDM of 212 g kg⁻¹ and 758 g kg⁻¹, respectively, for leaves, which was similar to alfalfa. However, the stems were low in CP (56 g kg⁻¹) and digestibility (420 g kg⁻¹), which lessens the overall forage value for the entire plant. Foster et al. (2009) reported pigeon pea raised in Florida contained 121 g kg⁻¹ CP, 695 g kg⁻¹ NDF, and 689 g kg⁻¹ IVDMD at final harvest. Rao and Northup (2012) noticed that cattle did not selectively graze primary and secondary stems of pigeon pea during a grazing trial, likely due to high lignin content and low digestibility. A later trial in Oklahoma recorded higher amounts of tannins in the stems of pigeon pea than in leaves (B. Northup, unpublished data, 2010). The by-products of split seeds for human consumption can provide a low-cost source of protein for animals compared with other sources of feed supplements such as fish and bone meal (Phatak et al., 1993).

The value of pigeon pea grown for grain and forage has been researched in Tennessee, Florida, Virginia, and Oklahoma. Results showed some degree of adaptation of pigeon pea in these different regions. Low water requirements and high drought tolerance indicates that pigeon pea would fit as a multi-purpose summer crop for the SGP. Early maturing varieties have the potential to provide grain and sufficient herbage of moderate nutritive value for grazing. Rao and Northup (2012) observed animal gains of 140 kg ha⁻¹ and average daily gain of 1.0 kg during late August through early September grazing bouts, compared with 0.5 to 0.75 kg d⁻¹ gain for warm-season grasses. However, there is need to develop new cultivars with greater leaf/stem ratios and finer stems to provide greater amounts of high nutritive value forage and allow longer grazing periods. In addition, systems-level water, nutrient, and economic budgets need to be evaluated so producers can make informed decisions regarding the use of wheat–pigeon pea rotations in the SGP.

CONCLUSION

The short list of discussed pulses represents a small segment of the entire population of under-utilized or neglected legumes that exist worldwide. In some cases, their value as forage could exceed the most common pulse (soybean) used in the SGP. Both tepary bean and mothbean were known for their remarkable drought tolerance in the early 20th century, but were neglected afterward. They are likely to be valuable in rainfed systems in the SGP, due to their excellent soil-covering ability and heat and drought tolerance. There is a need to evaluate the capacity of cultivars of these two species from different regions of the world to examine their adaptability to the varied growing conditions that exist in the SGP.

Cowpea has been a commonly used summer cover crop by producers in the drier regions of Oklahoma and Texas where other legumes rarely succeed. Mungbean has also shown high forage yields and nutritive value, but is less drought-tolerant than cowpea. Thus, mungbean may fit well in eastern parts of the SGP, which receive more precipitation during summer. The US grain market for both cowpea and mungbean crops is expanding due to increasing Asian and African populations and shifts in dietary preferences. Therefore, their grain production may also provide some potential for producers to generate improved cost–benefit ratios.

Seed of guar is also in high demand due to their industrial uses, but the nutritive value of guar forage declines with maturity. There would be tradeoffs between the values of grain crops and forage value of guar if producers chose harvesting hay at maturity. Studies involving overall economic analysis of animal gain and grain production can bring more insight on value of guar in the SGP. Pigeon pea has shown its ability to produce grain and forage with moderate nutritive value that supports animal gain compared with traditional warm-season grasses. However, developing new cultivars with greater leaf/stem ratios can further improve nutritive value and allow lengthier grazing periods.

In general, all of the discussed crops show potential of use as components of different strategies to increase precipitation use efficiency, minimize soil erosion, meet N requirements for following crops, and build organic matter and soil structure. Examination of management practices to define best practices for growing these novel crops and their comparison to more commonly used pulses are required. Further, systems-level water, nutrient, and economic impacts of growing these crops in rotation with winter wheat need to be evaluated for optimal enhancement and improved overall effectiveness of forage–stocker systems.

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