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SUSTAINABLE, LOW-INPUT WARM SEASON PASTURE GRASS-LEGUME MIXES: MISSION (NEARLY) IMPOSSIBLE?

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INTRODUCTION

If inputs are not limiting, it is easy to grow abundant forages on nearly any piece of land. Irrigation, fertilizers, herbicides, insecticides, mowers, continuous cultivation, annual seed inputs, and low stocking rates are examples of management options which maximize forage production on a given piece of land. Only when inputs are inexpensive and/or animal product prices high, however, is this approach economically feasible. This optimal economic scenario rarely occurs and as a consequence, pasture and rangeland managers are usually forced to design and manage pastures and rangelands that are self-sustaining without continual inputs yet yield sufficiently to feed themselves and society at large. Mixing grasses and legumes top this list of management options.

Under most circumstances grasses will out-yield herbaceous forbs such as legumes (Pitman et al., 1992; Whitbread et al., 2009) and provide greater amounts of digestible fiber to ruminants than legumes (Maasdorp and Titterton, 1997). Grasses have fibrous root systems that give them an advantage to capture shallow moisture and minerals from the soil. They also tend to establish more easily, grow more rapidly, and recover from grazing more quickly. Unfortunately, grasses mine soil nutrients which grazers translate into animal protein (Phillips, 2009). If subjected to heavy grazing pressure, native or cultivated grasslands can deplete the soil such that the entire ecosystem will deteriorate and eventually collapse.

Forbs have their advantages and drawbacks as well. In the case of legumes, the ability to fix atmospheric nitrogen (N) is an asset to infertile soils or low-input systems such as native grasslands (Piper, 1998; Temperton, 2007). In addition, legumes have taproots that, especially in the case of perennials, allow them to penetrate deeper into soil profiles in search of moisture. Their disadvantages include slow recovery from herbivory, low seed production, and seedling vigor compared to most grasses. But under reasonable grazing pressure, natural grasslands sustain forb populations which contribute diversity and biomass (Weaver, 1954). This may surprise the modern land manger accustomed to thinking of ideal pasture as monoculture.

Warm-season mixtures of grasses and legumes have advantages over monocultures only when they bring together the benefits of both components while minimizing their disadvantages (Piper, 1998; Gerrish, 2003). ***The goal is to maximize natural resource utilization to produce animal products in a sustainable manner.*** Native warm-season, sub-tropical and tropical grasslands throughout the world, if free of human interference, contain a rich diversity of both grasses and forbs (Fabian and Germishuizen, 1997; Diggs et al., 1999; van Oudtshoorn, 1999). Remove broadleaf herbicides, excessive grazing, and heavy fertilizer application from cultivated monoculture grass pastures and soon these also contain increasingly rich diversity. When cultivated or native pastures function as designed, grasses provide most of the digestible energy while legumes, usually a minority component, contribute crude protein (CP) and together they maximize animal performance (meat, milk, etc.) with minimal inputs (Pitman et al., 1992; Maasdorp and Titterton, 1997).

Our objective then becomes what appears to be deceptively simple: design and manage warm-season pastures and rangeland grass/legume mixtures which yield meat, milk, and other products with minimal input year in and year out. Achieving this is far more challenging than one would expect, mostly because our European-style ruminant *production* systems are geared not to sustainability but to extracting *product* by *producers*, just as the system's name implies. If land managers take a step back from this singular focus on land exploitation such that broader, long-term husbandry guides their pasture and rangeland management, they will be much closer to stable, balanced and productive warm-season mixed species pasture and rangeland ecosystems.

DESIGNING MIXTURES

Planning, planting and managing mixtures of forage grasses and legumes that are both productive and persistent is far more difficult than focusing on single-species pastures. If we understand a few basic principles, however, these difficulties become less daunting.

Rhizomatous/stoloniferous grasses vs. bunchgrasses

Where annual rainfall exceeds 800 mm, sod-forming grasses tend to predominate in cultivated monoculture pastures (Moser et al., 2004). Bermudagrass (*Cynodon* spp.) and bahiagrass (*Paspalum notatum*) are prime examples found in southern portions of central and eastern North America. These are widely used because they are adaptable to many soils, climates, and management systems. In other words, these grasses persist because they are forgiving of abuse. The very fact that they are aggressive invaders makes them poor choices for consociation with legumes. Only in low nitrogen soils do legumes stand a chance of surviving alongside sod-forming grasses (Valencia et al., 1999) and, even then, grazing management must be such that cattle, sheep, goats, or white-tailed deer are not allowed to selectively graze legumes out of the mix.

Bunch grasses tend to dominate grasslands where annual rainfall is less than 800 mm and soils are well drained (Diggs et al., 1999; Moser et al., 2004). Their advantage in mixtures is that they allow forb seedling establishment in the space between plants; their disadvantage is that they do not tolerate over-grazing when young and have poor nutritive value when mature (Muir and Jank, 2004). There are numerous native, warm-season bunchgrasses presently available on the introduced pasture and native rangeland seed market. These include various switchgrass cultivars (*Panicum virgatum*), Indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), big bluestems (*Andropogon gerardii*), sideoats grama (*Bouteloua curtipendula*), and eastern gamma grass (*Tripsacum dactyloides*). Introduced bunchgrasses include buffelgrass (*Cenchrus ciliaris*), kleingrass (*Panicum coloratum*), WW-B Dahl (*Bothriochloa bladhii*), and love grasses (*Eragrostis* spp.).

Spacial vs. temporal mixtures

Another consideration when formulating grass/forb mixtures is whether to have them in direct competition with each other or to separate them by time or space. In very rare cases legumes out-compete grasses (Valencia et al., 1999), but the opposite is usually the case. If grasses are simply too competitive, protecting legumes by over-seeding them onto dormant grass is one proven strategy (Evers, 2009). It can be argued whether this is a genuine mixture or not, but growing cool-season legumes on the same land but at different times from a warm-season perennial grass is a useful strategy.

Planting legumes in strips free of grass is another approach (Adjei, 1995; Muir and Pitman, 2004; Whitbread et al., 2009), but the width of each strip and palatability differential needs to match species compatibility as well as animal production objectives. Some research indicates that separating grasses and legumes over space decreases yields vis-à-vis mixtures (Shehu and Akinola, 1995); however, it is less difficult to manage grazed forages when they are separate. For example using legumes in forage banks instead of in mixtures (Muir, 1993) greatly increases the chance that both the grass and the forb will persist.

Match-making

Species selection, planting patterns, and grazing strategies can make all the difference when designing stable pasture or rangeland mixtures. The more complimentarity among species, the more likely that mixes will out-produce monocultures (Aarssen, 2001). Grasses generally have the advantage when grown in close proximity to legumes but this competition can be mitigated by selecting legumes that can, for example, tolerate shade if they are shorter (Muir and Pitman, 1989; Muir et al., 2009), climb up grass structures (Maasdorp and Titterton, 1997; Muir et al., 2005a), etiolate into the grass canopy (Muir et al., 2005b), or outgrow the grass in low-fertility soils (Valencia et al., 1999).

Palatability, which varies considerably among legumes in particular (Sheaffer et al., 2009), also plays a role in designing a stable mixed forage ecosystem. In a pasture or rangeland where animals will do the harvesting, mixing grasses and legumes with fairly similar appeal or accessibility to the grazer is essential if the system is to maintain a constant ratio. Knowing the preferences and grazing strategies of the ruminant species is also important. A white-tailed deer will select different plants from within a mixture than a horse or cow.

If a perfect match is not possible, then grazing strategies that force animals to graze all species equitably before moving on can sometimes level the playing field. This can be achieved through rotational grazing, successive waves of selective versus bulk grazers, or hay harvest following short-duration grazing (Sollenberger et al., 1987a; Sollenberger et al., 1987b) .

WHAT WE KNOW SO FAR

Our accumulated experience to date has taught us several general principles that we can use in our search for sustainable grass/legume mixtures:

1. **Perennial systems tend to foster diversity** and are therefore likely more stable than annuals (Tilman et al., 2006). Disturbed ecosystems seeking long-term equilibrium will tend towards complexity. If properly managed, by either nature or man, forage and rangeland plant mixtures will recruit diversity; conversely, poorly managed pastures and rangeland will deteriorate towards mono-specific plant communities where the most aggressive, least palatable survive all others in the original mix.

2. **Nitrogen fertilizers lead to grass dominance** and decreased species diversity**.** If legumes and general diversity are to survive in mixtures with grasses, the latter cannot be heavily fertilized with N (Andreata-Koren et al., 2009). Because legumes fix their own N, they gain an advantage in low-N systems that endow them with additional survival vis-à-vis companion grasses.

3. **Low inputs lead to lower yields.** Low input systems such as rangelands and even binary pastures can generally maintain more balanced mixtures under low input management. The price, of course, is lower productivity per area.

4. **Sustainable, low-input multiple-species pastures are complex.** This complexity lends stability over time but also requires deeper knowledge and greater analysis from managers if mixtures are to be maintained over the long term. Increased complexity in animal species, such as a combination of grazer and browser species, both domesticated and wildlife, can also benefit plant community diversity (Vangilder et al., 1982; van Rooyen et al., 1989; Rutter, 2006).

5. **Managing plants means managing animals and soils**. The initial choice of species to plant together is important, but to maintain the balance of that mixture over time, managers must learn to manage animals (stocking rates, grazing duration, species mixtures) (Rutter, 2006) as well as the soil under those plants (fertility, organic matter, micro-organism health) (Eisenhauer, 2009). This requires far greater knowledge and experience than the traditional monoculture approach.

6. **A shotgun approach** may sometimes work when insufficient information is available. Including multiple grass species and multiple legume and other forb species in pastures or rangeland with varying slopes, soils, weed pressures, or grazing pressure may result in a less uniform pasture but can also result in greater successful establishment across the entire diverse landscape.

7. **Diversity equates to more even forage distribution and nutritive value** over seasons and years. As climate changes over the year and as one group of species in the mix fades, others fill in the gap (Gerrish, 2003). This is driven by differential climate adaptation, growth patterns, reproductive strategies, among other factors.

WHAT STILL NEEDS DEVELOPMENT

Land manager education

The most sustainable warm-season and tropical pasture and rangeland systems around the world are a result of accumulated knowledge gleaned from generations of managers (Hardesty and Box, 1984). If that knowledge flow between generations is interrupted or social values change, the systems tend to collapse. The degradation of North American mixed grass/forb rangeland ecosystems in the last 200 years is a result of drastic socio-cultural change from Native American to northern European cultures as well as the lack of sufficient number of generations from which lessons learned can accumulate and guide future generations.

More adapted native and introduced warm-season legumes

We have numerous exotic and native grasses to work with. By contrast, very few introduced legumes, sufficiently adapted to warm-season North American edapho-climatic conditions, exist that can persist in mixtures with grasses in warmer latitudes. Those that are widely used, such as *Sericea lespedeza* (Mosjidis, 2001) and *Arachis glabrata* (Valencia et al., 1999), are usually found in monocultures but contribute to well-managed mixtures. A concerted effort to find additional candidates for pasture mixtures may correct this but only with greater investment in time and risk.

Native legumes are candidates for rangeland restoration as well as cultivated pasture mixes. However, there is a paucity of commercially available native herbaceous legume seed collected from warmer latitudes of North America. Illinois bundleflower (*Desmanthus illinoensis*), partridge-pea (*Chamaecrista fasciculata*) and more recently, *Desmanthus bicornutus* (Ocumpaugh et al. 2004) are presently the only available species. None of these are as yet widely recommended in cultivated pasture seed mixes due to lack of seedling vigor, low productivity and persistence, and anti-quality factors (Posler et al. 1993; Berg 1996; Jackson 1999; Nguluve et al. 2004). Some natives recently researched include the annual smooth-seeded wildbean (*Strophostyles leiosperma*) as well as perennial mimosa (*Mimosa strigillosa*), tickclovers (*Desmodium* spp.), prairie acacia (*Acacia angustissima*), prairie-clover (*Dalea* spp.), prairie bundleflower (*Desmanthus leptolobus*), leadplant (*Amorpha canescens*), and false indigo (*Amorpha fruticosa*) (Posler et al., 1993; Muir and Bow, 2008; Muir et al., 2008). To date, none have proven compatible with sod-forming grasses while a few that are able to establish in native perennial bunchgrasses (Posler et al., 1993; Muir and Pitman, 2004) have yet to be proven persistent under grazing over the long or even medium term.

CONCLUSIONS

Our experience to date with grazing legumes in native grass/legume stands and failing to establish many legumes with grasses in cultivated warm-season pastures reflects the difficulties of multiple-species pasture management. The science of establishing mixtures has yet to be developed and the art of maintaining the mixtures once established is even further outside our experience to date. This should not discourage us from trying; if natural warm-season grassland ecosystems, left to themselves, have scores of native grasses and forbs in stable ecosystems, we should be able to emulate them once we have identified the germplasm and management principles that have so far escaped us.

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Plant Diversity and Multifunctional Management of Grassland Agriculture

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Forage and grazing lands function to provide food, feed, and fiber and to conserve soil and protect water quality. Forage and grazing lands are increasingly expected to provide ecosystem services beyond the traditional provision of food, feed, and fiber. In a society focused on "green" issues, farmers and ranchers will be challenged to grapple with managing these lands for additional emerging ecosystem services, including biodiversity conservation, carbon (C) sequestration, mitigation of greenhouse gas (GHG) emissions, and bioenergy production. For example, national goals call for the production of 76 billion liters of advanced biofuels by 2022, which will require new perennial energy crop systems based on forages.

Managing for multiple ecosystem functions and services requires greater ecosystem diversity and complexity (Duffy et al. 2008; Zavaleta et al. 2010). In this paper, I provide a brief perspective from our research conducted in the northeastern U.S. on managing plant species diversity in forage and grazing lands to meet multiple ecosystem services.

Traditional Ecosystem Services of Forage and Grazing Lands The traditional ecosystem services derived from forage and grazing lands—food, feed, fiber, forest products, milk, and meat—generate a large portion of agricultural income in the U.S. Forage and grasslands account for about $45 billion of forage-livestock receipts, with about $11 billion from the 25.2 million ha of hayland. Forage and grazing lands supply feedstuffs for approximately 100 million ruminant animals on U.S. farms. Forage and grazing lands also provide critical conservation ecosystem services. Managed grasslands are critical to multiple soil and water conservation practices such as windbreaks for reducing wind erosion, vegetative barriers for trapping sediment and reducing water erosion, filter strips for slowing surface runoff and reducing herbicide movement, and buffer strips for protecting riparian zones. Many federal and state conservation programs in the U.S. recommend the use of multiple grass and legume species for conservation practices, such as the Conservation Reserve Program (CRP), the Environmental Quality Incentives Program (EQIP), and the Conservation Stewardship Program (CStP).

Pastureland Biodiversity for Ecosystem Services Biodiversity is recognized as a key feature of properly functioning ecosystems. Biodiversity can provide essential functions in agricultural grasslands (Sanderson et al. 2004). For example, legumes fix nitrogen (N), which may be used by associated grasses and other species in mixed species communities and replace the need for commercial fertilizer N. Maintaining competitive species in mixed plant communities can provide resistance to weed invations. Current pastures in the northeastern U.S. approach the species richness of European native cool-season grasslands, with a mean species richness of 31 species 1000 m^{-2} (Tracy and Sanderson 2000). Total species richness varies widely, from 9 to 73 species per pasture (Goslee and Sanderson, 2010). A few common forage species (9 to 12 per pasture) make up most of the cover; the remaining species are generally rare. Biodiversity within pasturelands provides indirect benefits by supporting ecosystem functions that may not be of direct agricultural importance in pastures, but contribute to the wider regional ecology. Another class of biodiversity benefits comes from the cultural values attached to particular plant and animal species, and from the maintenance of diverse grasslands as a component of the landscape. Thus, conserving, preserving, and enhancing biodiversity of natural and managed ecosystems is of great importance.

In addition to maintaining biodiversity for conservation purposes, managing biodiversity for production purposes is an agro-ecological approach to grassland farming. Herbage yield benefits for biodiverse mixtures of forages have been demonstrated in small-plot research (Skinner et al. 2004; Tracy and Sanderson 2004a; Deak et al. 2007; Deak et al. 2009; Picasso et al. 2008; Skinner 2008a), pasture-scale studies (Sanderson et al. 2005; Skinner et al. 2006), and economic analyses (Sanderson et al. 2006; Deak et al., 2010). The yield benefit realized from using diverse mixtures often resulted from including highly productive, drought-tolerant species, supporting the idea that species traits are more important than species numbers in forage mixtures. Similar results for diverse forage mixtures have been demonstrated in Europe (Kirwan et al. 2007).

Grazing management links primary and secondary productivity of pasture-based animal production systems. Sward productivity and nutritive value are not realized unless the grazing animal can efficiently ingest and utilize the herbage. Animal productivity trials on botanically diverse pastures have shown variable beef cattle gain responses (Tracy and Faulkner 2006). Milk production, herbage intake, and ingestive grazing behavior (grazing time, biting rate, and grazing jaw movements) were similar for high-producing dairy cows grazing diverse swards compared to lower diversity swards (Soder et al. 2006; 2007).

Plant species diversity could be used in weed management by targeting appropriate combinations of forage species with specific functional traits to reduce the establishment of invasive plants (Drenovsky and James 2010). Greenhouse, field, pasture, and survey research demonstrated that weed invasion can be reduced by using species-rich forage mixtures (Dodd et al. 2004; Tracy et al. 2004; Sanderson et al. 2005; Kirwan et al. 2007; Picasso et al. 2008). Weed abundance decreased in experimental pasture mixtures as the evenness (i.e., the relative abundance of individual species in a mixture) of forage species increased (Tracy and Sanderson 2004b).

Emerging Ecosystem Services from Forage and Grazing Lands Carbon storage and GHG mitigation will be important ecosystem services to be derived from agriculture in the future. Currently, agriculture is responsible for about 7% of total U.S. GHG (CO_2, CH_4 and N_2O) emissions. Improved pasture management could increase the quantity of C sequestered in soil by 10 to 34 Tg per year in the U.S. (Follett et al. 2001). The potential of forage and grazing lands to sequester C can be influenced by management such as grazing or mowing frequency, stocking rates, plant species composition, age of the stand, and soil fertility (Schnabel et al. 2001). For example, intensively managed pastureland in the U.S. did not provide a consistent sink for C during several growing seasons. Four years of monitoring C flux on pastures in Pennsylvania showed that mature pastures can be a C source at typical forage utilization levels (Skinner 2008b). In that study, pastures were substantial C sinks only in April and May. Other studies have also found pastures to be C sinks for only a short period each year (Ammann et al. 2007). A study of nine European grasslands showed wide variation in net annual C accumulation, ranging from a loss of 2.66 Mg C ha^{-1} yr^{-1} to a net gain of 4.62 Mg C ha^{-1} yr^{-1} (Soussana et al. 2007). Delaying forage harvest by cutting or grazing as late as possible during spring could maximize the C sink; however, that would involve a significant tradeoff in forage nutritive value and animal performance (Skinner 2008b).

Carbon footprint estimates of different dairy production systems with a whole-farm simulation model suggested that a system of grazing dairy cows from April to October combined with winter confinement had lower GHG emissions than either a full confinement system or year-round grazing system (Sedorovich 2008). The year-round grazing system had lower CO_2 emissions than the confinement system, but had greater N_2O emissions. Both the year-round system and the combined grazing+confinement system, however, had lower net economic return per cow compared with a full confinement system suggesting that scenarios resulting in the lowest GHG emission may not be the most profitable.

Bioenergy Production and Implications for Forage and Grazing Lands. The bioenergy industry of the future will rely on dedicated energy crops based on perennial grasses (Sanderson and Adler 2008; Adler et al., 2009). Perennial biomass crops are often more favorable than annual cropping systems in terms of net energy return and reduction in GHG emissions (Adler et al. 2007; Schmer et al. 2008). The perennial grasses are particularly compelling because of their relatively low production inputs and costs, perennial growth habit, and adaptability to a broad range of growing conditions.

In the U.S., national goals for renewable energy call 76 billion gallons of advanced biofuels by 2022, which would require an annual biomass supply of 907 Tg (1 billion tons). The projections for bioenergy cropping in 2022 to meet this goal have significant ramifications for future forage-livestock production systems. For example, the assumptions for increased crop yields and new technologies are likely optimistic, which means that more land area will be required to produce the targeted biomass than anticipated. Similarly, if less cropland were converted to perennial energy crops, then the production of perennial energy crops could be forced to more marginal lands. In the Chesapeake Bay region of the U.S., scenarios of replacing up to 0.4 Mha of pasture and hayland with switchgrass for bioenergy have been proposed (Chesapeake Bay Commission 2007). This would also force forage-livestock production to other regions or cause greater intensification of confined animal production.

Significant land use change from converting grasslands to bioenergy production as a result of biofuels targets have raised concerns about environmental consequences in the European Union (Taube et al. 2007; Peeters 2008). In the U.S., projections of expanded ethanol and biodiesel production indicate large reductions in pastureland (De La Torre Ugarte et al. 2007). And, other international analyses of land use and availability suggest converting pastureland to biofuels production (Fischer et al. 2010; Smeets et al. 2007). If these projections are realized, there will be tremendous pressures on hay, forage, and pastureland in the future. The expanding need for biomass production would probably force forage and grazing land production to more marginal lands.

Summary Agricultural systems based on diverse grasslands have a number of environmental benefits, including soil conservation, improved nutrient cycling, and provision of wildlife habitat. Diverse grasslands can support and even improve livestock production and health. Biologically diverse systems could provide a range of newly-emerging services, including C sequestration and biofuels production. But it must be remembered that as with most agricultural production systems there are tradeoffs between achieving production levels necessary to meet the farmer's economic sustainability, while at the same time satisfying the demands of an expanding population that wants to eat meat and drink milk, and maintaining the integrity of the agroecosystem.

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Small Acreage Landowners: The Next Generation Rancher

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The small farm owner is a growing segment in Texas agriculture. Per the Ag Census statistics, 33 % of all farms and ranches in Texas are ranked under 50 acres in size. The small-scale farm or ranch owner may have purchased the operations for many reasons, retirement, and a source of alternate income, or to impart a life-style change. Small-scale farmers/ranchers many times have arrived in the enterprise with the need for education concerning enterprise choices, basic production guidelines, as well as advice on marketing strategies and agricultural legalities.

It's a Number Game

The U.S. Department of Agriculture defines small farms as farms with $250,000 or less in sales of agricultural commodities. According to the 2007 Agriculture Census, there were 18,467 more small farms counted then in 2002. The number of small farms counted in 2007 was 1,995,133 or 91 percent of all farms. The percentage of small farms has historically been the highest in the South and New England. Farms with sales less then $10,000 have increased while farms with sales of more than $10,000 have decreased. Operators of farms with sales of less than $10,000 typically work off farm. This typically occurs when someone with a full time career, more often than not they are lawyers, doctors and business men, buys property outside of town and "hobby farms." Some of the small farm owners have actually been farming large acres for years but for various reasons have decreased their acreage. Sometimes a farmer's place of business is also his or her residence. This means that they have greater incentives to continue farming, but may gradually lighten their workloads and/or reduce the acreage they operate as they age.

United States farms with sales between $100,000 and $249,999 decreased by 7 percent from 2002 to 2007 and operators of these farms were younger than average and were more likely to be full time farmers. Granted these statistics account for all small farms not just small livestock/forage producers. According to the 2007 Census, the largest category of production for farms with sales between $10,000 and $99,999 was beef cattle and calves followed by grains and oilseeds. More than half of the farms that produced less than $10,000 were beef cattle or "other crop" farms. That category-included hay farms and farms where no single crop comprised more than 50 percent of sales.

Defining Moments

USDA defines beginning farmers and ranchers as those who have operated a farm or ranch for 10 years or less either as a sole operator or with others who have operated a farm or ranch for 10 years or less either as a sole operator or with others who have operated a farm or ranch for 10 years or less. Beginning farmers tend to be younger than established farmers and to operate smaller farms or ranches, some of which may provide no annual production. Beginning farmers often face obstacles in getting started financially; learning about management, and often times understanding the science of agriculture.

The average age of all U.S. principal farm operators in the 2002 Census was 55.3 years of age. At the other end of the spectrum, the percentage of principal operators with average ages of less than 35 years has been declining since 1982, when it was 15.9 percent, and was only 5.8 percent in 2002. Principal farm operators of farms 49 acres in size or smaller and those with farms of 500 acres or more had average ages less than the 55.3 overall average. The highest average ages (57.0 years or higher) were owned between 140 and 259 acres. With a struggling economy more youth are attending college in order to increase their chances of a high-income career and fewer are returning to the family farm. Beginning farmers are somewhat more likely than established farmers to have a 4-year college degree. Obtaining a college education may prevent younger family farm members from immediately taking over or helping to operate the family farms. In 2007, more than 60 percent of established farmers were over 55 years old, compared with 32 percent of beginning farmers. Nationwide, only 5 percent of principal operators were under the age of 35, but 17 percent of beginning farmers were under the age of 35.

More than likely a majority of small landowners are retired or picking up ranching as a hobby in addition to a career. Rarely do these small landowners have any type of agricultural background. There is a generation of small landowners that are inheriting land from family that did ranch/farm full time. However, as children they had no direct involvement. They remember the idealistic moments and not the realistic ones. Maybe these ideals are what attract them back to the ranch/farm. As educators we must unfortunately bring these freshman farmers back to reality. Often times this land that has been inherited may have originally been large in acreage however once it's been split amongst siblings, you often end up with 2-3 new small landowners.

Last will and testament

A recent conversation with a woman who had inherited her fathers ranch along with her 2 other siblings. Each sibling had a different idea, plan, and goal for the land they recently inherited. One sibling had apparently paid attention while growing up on a ranch and seeking no guidance. The one that called seeking guidance had a different set of goals compared to her sibling. She preferred the more ecological route of agriculture. Guidance had to be carefully altered to meet her needs. Her lack of agricultural background, her management goals that leaned towards organic and the fact that this was not going to be a primary source of income for her had to be factored into a response. This is challenging considering that 90% of extensions time deals with ranchers that have been in the business for years and have a strong agriculture background. They typically only require the education that fine-tunes their already existing systems.

The land grant University mission is education, research and extension. Small landowners need education all the way from the basics of soil testing to marketing their livestock. Research has already unveiled forage data that can be condensed to fit the small landowners needs/goals. Extension has to reach out to this new market of farmers/ranchers and provide necessary information. We are use to working with producers who already have a base knowledge. We have become experts at providing them information for fine-tuning their production systems. Now with the modern rancher big ideas have to be translated to a smaller scale and knowledge has to be passed to someone with no agricultural background (typically). Small landowners often have different goals than larger landowners. A rancher striving to make a living needs a different perspective as opposed to a rancher striving to fill his or her free time. Not every small landowner has an expendable income so that must not be assumed.

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Challenges for Forage Production on Small and Limited-Resource Farms in the Southern Plains.

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Small livestock farms in the southern plains are frequently characterized by low productivity and limited farm-derived income. The majority of producers are obliged to resort to off-farm employment to generate a living income (or in many cases to subsidize their farming activities). Many small livestock enterprises are located on land degraded by cultivation in the early part of the 20th century, or on otherwise marginal land of inherently low productivity. Forage resources are primarily remnant or re-established unimproved native pasture, and some improved warm-season grass, notably bermudagrass. Over-stocking on small farms is a widespread problem, with consequent overgrazing, reduction of forage output, increased weed burden and costs of purchased feed necessary to cover forage deficits. Recent focus has been given to increased use of cool-season forage, in order to extend the period of grazing and reduce costs of winter feeding.

Small livestock producers have limited time or material resources to increase enterprise productivity through increased production of forage and few own, or have easy access to, field equipment for cultivation and sowing forage crops. Forage management practices are generally risk-averse, because of the uncertainties of success of crop establishment or of economic viability of input use.

Projections of increased variability in temperature and precipitation imply greater uncertainty for small farm operations that will result in even greater difficulty in producing adequate forage than is experienced under existing conditions. Some possibilities for increased forage production or improved seasonal distribution that also offer some mitigation of risk are discussed below.

Introduction of cool-season forages into a system based on warm-season pasture offers a possibility of increasing total annual forage output as well as improving seasonal distribution of production to allow a longer grazing season. However, on low-productivity land typical of small livestock producers in central Oklahoma cool-season grasses normally considered to be perennial forages have shown limited persistence and low lifetime productivity, at a level that cannot justify establishment costs. Establishment of cool-season perennials by conventional tillage and sowing (i.e. by destruction of existing pasture) actually reduced 4-year total forage production compared with undisturbed existing warm-season pasture. In contrast, annual ryegrass overseeded into existing warm-season pasture has consistently increased total annual forage production, by an average of approximately 20%, over yields achieved with undisturbed warm-season pasture. By retaining existing pasture not only may year-round production be increased by overseeding cool-season grass, but the risk of production loss arising from establishment failure of the cool-season crop is minimized. In a worst-case, failure of the overseeded crop will result in loss of incremental cool-season production but existing warm-season pasture will remain to produce forage during the warm-season. Retention of existing pasture may also have important collateral benefits for increased water infiltration, reduced soil erosion and increase surface stability and ease of access for livestock.

Loss of investment in input costs represents a significant component of risk for small producers. If input costs can be minimized, then perceived exposure to risk may also be reduced. Overseeding using a no-till drill eliminates costs of tillage, but no-till seeding equipment may not be easily accessible by small farmers. Broadcast seeding can be achieved with a minimum of equipment and is likely to be completed in less time than with drilling equipment. Annual ryegrass can be established almost as effectively by broadcast seeding as by drilling, with little difference in eventual forage yield. Other cool-season annual forages (small grain cereals) are not only less amenable to broadcast overseeding, but require significantly greater seeding rates and higher seed costs than annual ryegrass, for similar forage yields, and therefore represent a greater risk for the small producer. Annual ryegrass may also re-establish by self-seeding, and may thus become a persistent forage with minimal input from the producer. The success of self-seeding is, however, variable in central Oklahoma where we have observed establishment failure in 40% of cases. Problems with re-establishment appear to result from occasional mid-summer rainfall that stimulates premature germination and subsequent seedling loss under the intense drying conditions in summer. Paradoxally, summer conditions that are consistently hot and dry may improve the success of perennation of cool-season grasses by avoiding premature germination in seeded crops or break of dormancy in summer-dormant species.

On low-productivity soils forage yield responses ranging from 15-30 kg DM/kg N in cool season grasses to over 40 kg DM/kg N with warm-season species have been observed. Responses to applied N are highly dependent upon availability of adequate soil moisture for crop growth, and uncertainty over moisture availability represents significant investment risk, and is a major disincentive to small farmers' use of N on forage crops. Legume use as an alternative N source is of potential interest to small farmers but slow establishment and limited persistence under small farm conditions mean that potential nitrogen contribution may be lower than is commonly assumed.

Increased use of cool-season forages can increase carrying capacity on small and limited resource farms and potentially diminish negative impacts of increased climatic variability on productivity of warm-season pastures. The success of cool-season forage production is also subject to the influence of climate, but short-term annual cool-season forage, established using minimal input methods may allow opportunistic use with minimum risk. Although a persistent perennial cool-season grass would reduce repeated cost and risk of establishment, compared with an annual, use of the latter allows flexibility to eliminate the cool-season component of a crop sequence if soil moisture is limited. Work is needed to examine ways to diminish competition between cool- and warm-season crops at seasonal interfaces and to evaluate compatibility under reduced-moisture conditions.

Climate Variability in the Southern Great Plains: It Gets More Exciting from Here

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The issues relative to climate variability, climate change, and forecasts of weather and climate are complex and challenging. It is easy to become confused in the jargon, data, forecasts, and contrasting opinions. Coherent guidance for practical applications is rare. In these few pages I offer information relevant to the question of how to manage pastures, especially on small or resource-limited farms, under increasing climate variability in the Southern Great Plains. In a nutshell, if we can learn to successfully manage for the variability that is occurring now, we should be well-positioned to manage for climate change over the next few decades.

Recent and projected increases in variability in climate and weather

When people speak of climate change, they are usually referring to trends in long-term averages over years, decades, or centuries (e.g., Livezey et al. 2007). Until relatively recently, climate studies assumed that climate was very close to constant, so variations were given less attention than averages. But it's the variations, season to season, year to year, that make or break agricultural operations, with droughts, floods, and unseasonable freezes as examples. Such variations are particularly pronounced in the Great Plains. Now we have physically based arguments as well as credible model projections that predict that a significant component of climate change will be increased variability — larger and longer swings in daily, monthly, seasonal, or annual conditions around the averages, as well as more frequent extreme events. In support of those projections, increasing numbers of analyses are being published that reveal such increases in variability in the last few decades.

One of these is the Climate Extremes Index (CEI, by Gleason et al., 2008), a measure calculated for the contiguous U.S. for years and seasons from 1910 through the present year. To summarize the authors' conclusions, recent years have been increasingly variable (excerpts from the abstract):

> "*The CEI is based on a set of climate extremes indicators that measure the fraction of the area of the United States experiencing extremes in monthly mean surface temperature, daily precipitation, and drought (or moisture surplus). ...Observations over the past decade continue to support the finding that the area experiencing much above-normal maximum and minimum temperatures in recent years has been on the rise, with infrequent occurrence of much below- normal mean maximum and minimum temperatures. …An increasing trend in the area experiencing much above-normal proportion of heavy daily precipitation is observed from about 1950 to the present. …Warm extremes in mean maximum and minimum temperature observed during the summer and warm seasons show a more pronounced increasing trend since the mid- 1970s. Results from the winter season show large variability in extremes and little evidence of a trend. The cold season CEI indicates an increase in extremes since the early 1970s yet has large multidecadal variability.*"

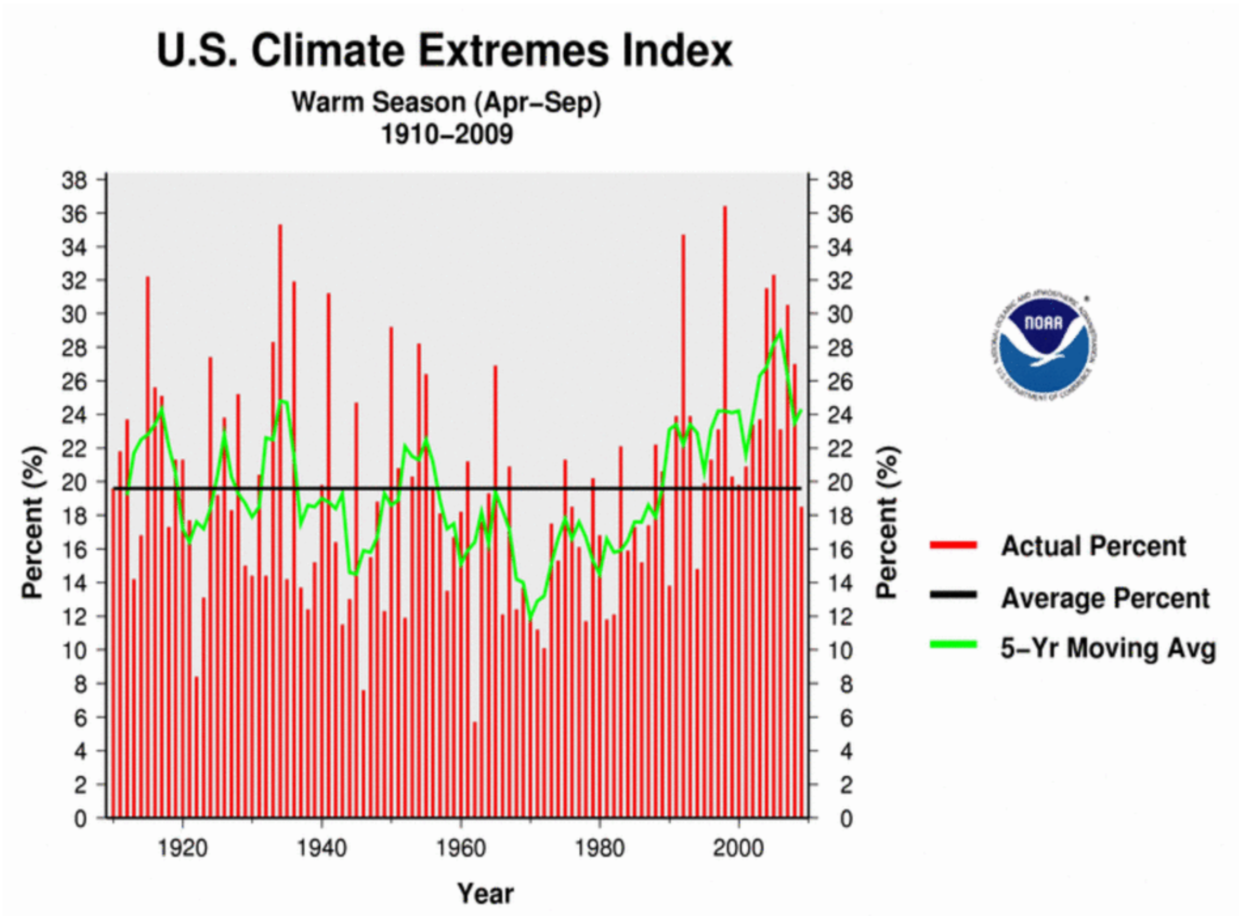

Figure 1. The U.S. Climate Extremes Index for the warm season computed across the contiguous U.S. from 1910 through 2009; from www.ncdc.noaa.gov/extremes/cei.html.

NOAA's National Climatic Data Center computes and publishes the CEI on their web site, and an example is shown in Fig. 1. This kind of measure gives a top-level overview, and is useful in that sense. Note, however, that it says nothing about what has been occurring in any given region or location within the U.S. Consideration of data on smaller spatial scales tells different stories, depending on where you are and which weather variable is of concern. Examples of variability in precipitation and average temperature over the last 40 years are available for the states of Kansas, Oklahoma, and Texas; for several climate divisions in those states; and two specific locations in Oklahoma (to be presented at the Conference). These examples illustrate that changes in variability are occurring, but not in the same manner across even the Southern Great Plains. The local details will matter for pasture management – it will be necessary to understand what is happening "in your neck of the woods" in order to develop useful decision support. Practically, this will mean using very local precipitation data rather than climate division data, but this is now possible using new precipitation products offered by the NWS. One example is the AHPS Precipitation Product, which offers radar-derived total precipitation on a 4 km by 4 km grid across the U.S. for the most recent day, one week, and longer periods through the year to date; this product is available at water.weather.gov/precip/.

Can we predict weather or climate variations with any skill or utility for agriculture?

(A few notes on terminology first. Weather and climate forecasts are issued for the U.S. by NOAA's National Weather Service (NWS). By the current NWS definition, "weather" refers to the atmospheric events that happen today or tonight, out to 7 days ahead; "climate" refers to cumulative events that occur over weeks, months, seasons, or years. All NWS forecasts beyond day 7 (climate forecasts) are predictions about changes in odds relative to a baseline period called "climatology" (currently 1971-2000). For example, instead of predicting how much precipitation will fall in the coming 6-10 days, they predict the odds for certain ranges of total precipitation. Precipitation refers to all the liquid and frozen forms of water that fall from clouds, and is measured and forecast in (melted) inches. Air temperature is measured a few feet above the ground in degrees Fahrenheit, with NWS climate forecasts referring to average temperature. The standard method to compute average temperature is to add the daily minimum and maximum, divide by two, then average those values over all the days in the forecast period: 6-10 days, 8-14 days, 1 month, and 3-month periods out to a year ahead. Note that this approach of averaging temperature or totaling precipitation over 5 days and longer fails to specify the extremes that are important in agricultural management.)

The answer is yes, although there are still real limits on which variables can be predicted skillfully, and how far ahead of time (see Schneider and Wiener, 2009, for related discussion). The NWS does issue relatively skillful 1-7 day weather forecasts on a grid of 4 km by 4 km for the contiguous U.S., available online at www.weather.gov. This web portal provides links to all the NWS forecasts, watches, warnings, advisories, and discussions, which can provide vital information about impending hazards and opportunities for anyone managing stock or pasture. The skill of most of the forecasts is very high at 1-3 day leads, and still very respectable out to 5 days. For days 6 and 7, the forecasts tend to be less skillful, but some useful clues can still be found in the Forecast Discussions.

The NWS also offers climate forecasts for total precipitation and average temperature at longer time scales: 6-10 days; 8-14 days; 1 month; and 3-month periods out to one year ahead (www.cpc.ncep.noaa.gov). Unfortunately, these forecasts do not have the useful place-specificity of the weather forecasts. They are offered only as low-resolution maps, or probability forecasts for large regions roughly half the size of the state of Oklahoma. Of these climate forecasts, the 6-10 day and 8-14 day forecasts appear to offer some skill in the Southern Great Plains, although the details of that skill are not yet known. The skill or utility of the 1-month and 3-month forecasts are lower yet, limited to certain regions, seasons, and depends on the ENSO state and strength (Schneider and Garbrecht, 2003, 2006, 2008; Livezey et al., 2008). A summary measure of 3-month forecast utility is offered in Fig. 2. The news is rather grim relative to the precipitation forecasts, especially for drought conditions. The only regions with potentially useful 3-month precipitation forecasts are the ones with significant ENSO impacts: the Southeast, southern Texas through the Desert Southwest, and the Pacific Northwest through the Northern Rockies. Conversely, climate forecasts for warmer-than average temperature over weeks to seasons is good during the cool season (November through March); not as good for extreme maxima (e.g., record-setting summer highs) and minima (e.g., unseasonable hard freezes); and are very poor for cooler-than-average conditions.

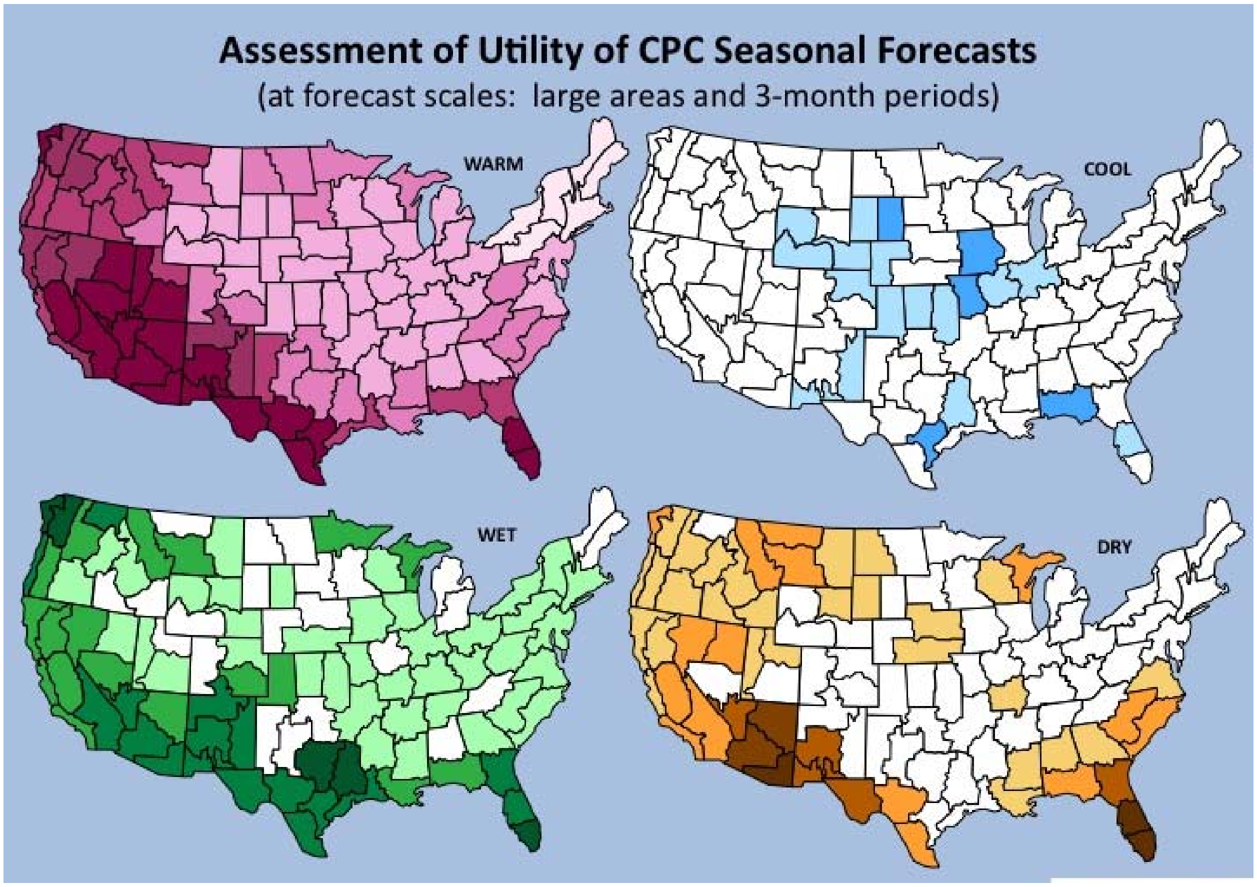

Figure 2. The more intense colors on the maps indicate the forecast divisions where NOAA/CPC 3-month forecasts have shown some potential utility for practical applications (summarized from Schneider and Garbrecht, 2006). The terms "WARM", "COOL", "WET", and "DRY" refer to forecasts for higher odds for warmer, cooler, wetter, or drier than average conditions.

Suggestions for developing climate-sensitive decision support for pastures

In a word, flexibility. For much of the U.S., the development of decision support for pasture management under increasingly variable climate still needs to be done. We need to define and create management options that can respond to the variations in weather and climate as they unfold, develop strategies that minimize the costs, equipment, and time spent on inputs when the odds of success are low, but produce as much forage as possible given the available soil water and soil and air temperatures. Concomitant goals would be to improve or maintain the ecological health of pastures, and avoid creating negative environmental impacts in pasture and downstream. Decision support for pasture management will necessarily use the skillful weather and climate forecasts, as well as readily available data on recent weather, in concert with knowledge of local conditions and realistic financial considerations.

For small farms or resource-limited operations, specific approaches might include:

1) developing more than one forage source (e.g., Bartholomew's approach of top-seeding warm season pastures with inexpensive annual rye for increased cool season forage) with

complimentary weather/climate requirements, to increase the probability of success;

2) preparing to adjust stocking rates, with the baseline rate lower than has been customary, seeking out inexpensive opportunities to increase stocking rate on a monthly basis if conditions and forecasts are optimal, or decrease stocking rate if conditions and forecasts are not;

3) developing a "windows of opportunity" approach to nitrogen application based on the particular mix of forages, recent conditions, and the more skillful forecasts, providing guidance on whether or not and how much nitrogen to apply, literally at the last minute.

Generally, in order to cope with increasingly variable weather and climate, pasture management will need to be dynamic, adjusting with the conditions and forecasts much more frequently than has been the norm. This will require a different mindset for many of us.

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Oklahoma Biofuel-Facts, Future, and Direction

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Oklahoma has an abundance of forage resources available. However, the adapted forage species and growth patterns vary considerably across Oklahoma due to the differences climatic patterns. Current land use trends reflect this forage production potential. Because of the forage resources available, Oklahoma has a large, diverse cattle industry that includes cow-calf production systems, stocker systems, as well as many purebred operations. Of the 44 M acres in Oklahoma, there are approximately 19 M acres (44%) classified as rangeland with 8 M acres (17%) classified as pastureland. Of the 10 M acres (22%) used for row crop production, it is estimated that as many as 5 M acres may also be used during certain times of the year, either as forage or supplemental forage production, to support livestock production. Although somewhat more difficult determine, it can also be assumed that a portion of the 6 M acres (15%) classified as forestland is used to support livestock production.

At one time, there was close to 20 M acres under cultivation in Oklahoma. Due to continued low commodity prices, increase in government programs to reduce crop production on highly-erodable lands, and change in the demographics due to increasing age of many producers, the number of acres formerly in row crop production have been reduced. This has resulted in approximately 10 M acres of land that was previously in row crop production that is currently defined as “go-back land”. It is difficult to determine whether or not these acres are currently classified as rangeland, pastureland, or forestland. However, it is likely that these acres are targeted primarily for forage production aimed for use as biofuel feedstocks.

The current emphasis on extension programming for biofuel/biomass production in Oklahoma has a somewhat unique focus. To avoid competition with the established livestock industry, much of the development of biofuel/biomass production in Oklahoma has focused on areas that were previously in row crop production or address issues from a cropping systems aspect. From a forage production standpoint, the *Switchgrass Production Guide for Oklahoma* was developed based on the continued interest in using switchgrass as a biofuel feedstock. This comprehensive guide is more traditional and addresses production practices including establishment, harvest management, as well as fertility and realistic yield expectations. Although not used in traditional forage systems, there are additional extension programming efforts aimed at using sweet sorghum (forage) cultivars as biofuel crops. To summarize the production scheme, these are managed as a rotation crop in a traditional cropping system. At harvest, the juice is squeezed from the stalks, with the resulting liquid fermented on site to produce ethanol.

Currently, there are limitations to developing a large-scale biofuel industry in Oklahoma. Many acres that could be used producing biofuel/biomass feedstocks are not suitable because of their low yield potential due high erosion potential, low water holding capacity, and unpredictable precipitation. Based on these factors, it is likely that most biofuel/biomass production in Oklahoma will be on a regional to local basis. Based on the agricultural history and climatic conditions in Oklahoma, new biofuel production systems should include traditional forages as components of those systems. Thus, continued efforts in forage programming will remain important to the development of these emerging industries.