Using Native Warm-Season Grasses in Forage Systems for Improvements in Ecosystem Services

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ABSTRACT

Hay and pastureland in the United States typically consists of introduced cool-season grass species. Many of these cool-season grasses are used due to their productivity, palatability, and tolerance of heavy grazing and aggressive hay harvesting. Biological characteristics of cool-season grasses make them less productive in the summer, potentially limiting cattle production. Native warm-season grasses use a different chemical pathway for photosynthesis than cool-season grasses allowing for them to have higher photosynthetic potential in the summer when temperatures are warmer. This literature review investigates the integration of native warm-season grasses in hay and pasture systems and the potential ecosystem services they may generate. Relevant, available research on native warm-season grasses and potential ecosystem service benefits in forage and livestock systems was reviewed and summarized by type of ecosystem service provided. Ecosystem service provisions were then compared to those of cool-season alternatives to determine the potential gains of native warm-season grass integration. Based on available literature, native warm-season grasses have the potential to be an integral part of future forage livestock agroecosystems in the United States due to the likelihood for overall productivity and environmental benefits.

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INTRODUCTION

Managed grassland for grazing occupies more than 33 million square kilometers or 25% of the global land surface, making it the single most extensive form of land use on the planet (Asner et al., 2004; Foley et al., 2005). Grasslands provide many valuable ecosystem services including: erosion protection, climate mitigation, food and products for human use, habitat for wildlife and pollinators and aesthetic value (Franzluebbers et al. 2012). The capacity for cool-season grasslands that provide forage for most beef cattle production in the eastern United States to provide ecosystem services may be limited. Cool-season grasses are less productive when temperatures rise in the summer, which can limit cattle production. This problem can be mitigated by adding diversity to cool-season grazing systems in the form of warm-season grasses, which are most productive in summer. Thus, diversifying grazing systems in the eastern United States may increase provisioning ecosystem services by increasing the efficiency and long-term sustainability of cattle production.

The use of native warm-season grasses (NWSG) in forage systems could improve efficacy of forage systems while promoting ecosystem services, multifunctional landscapes and sustainability. This research paper will aim to evaluate the hypothesis that the use of NWSGs in forage systems will increase the output of certain ecosystem services when compared to traditional management.

NATIVE WARM-SEASON GRASSES

Definition

A native plant is a species that has developed in a particular region or ecosystem as a part of the balance of nature over thousands of years or more. Each geographic region will have differing native species than other geographic regions. In other words, the term 'native species' is relative to the specific geographic region that is being referred to. Native warm-season grasses are a group of bunchgrasses that are historically indigenous to an area and are most productive during the warmer period of the year. Bunchgrasses tend to produce clumped and erect growth of tillers rather than spreading (Allen et al., 2011). Numerous species of non-native grasses such as *Schedonorus arundinaceus* (also *Festuca arundinacea*) (tall fescue), *Dactylis glomerata* (orchardgrass), *Cynodon dactylon* (bermudagrass), *Digitaria* spp. (crabgrass), *Paspalum dilatatum* (dallisgrass), and *Paspalum notatum* (bahiagrass) have naturalized and thrive in self-perpetuating populations in nature (Harper et al., 2007).

Rangelands are grasslands typically dominated by naturally occurring grasses and herbaceous species whereas pasturelands are devoted to production of forage and commonly are dominated by introduced species (Sprague, 1974; Allen et al., 2011). Native grasses are prevalent in native grasslands of the United States and have the potential to be established in pasturelands as forages and environmental resources. Tallgrass prairies, a type of natural grassland, were once vast in the southeastern United States and were dominated by NWSGs. Notable grasslands also existed in burned areas and rocky outcrops within the forests of the northeastern United States (Miller & Dickerson, 1999). Tallgrass prairies primarily consist of warm-season grasses, including *Andropogon gerardii* (big bluestem), *Schizachyrium scoparium* aka *Andropogon scoparius* (little bluestem), *Panicum virgatum* (switchgrass), *Tripsacum dactyloides* (eastern gamagrass), and *Sorghastrum nutans* (indiangrass) (Moser et al., 2004; Keyser, 2016). Native prairies also consist of a large proportion of forbs, primarily wildflower species. Losses from agriculture and land development have deteriorated the native grassland region of North America to 4% of its original extent (Moser et al., 2004). Grazing by bison, flood, and fire maintained natural grasslands at early succession. In the early 1800s, many of these grasslands were lost due to conversion to plowed croplands and overgrazing by livestock. Native warm-season grasses were replaced with now naturalized species, in some cases due to increased tolerance of intensive grazing (Ryan & Marks, 2005). Unfortunately, this reduction of variability in favor of the most productive and palatable cool-season forage species and associated grazing management may actually limit livestock production and forage sustainability due to rangeland degradation (Fuhlendorf & Engle, 2001). The suppression of fire exacerbated the decline in NWSGs, which rely on fire for maintenance. Land use changes today continue to eradicate native grasslands (Ryan & Marks, 2005). Such rapid degradation has limited the capacity of rangelands and pasturelands to provide essential ecosystem services (Blanco-Canqui & Lal, 2010). Unfortunately, over time naturalized forage species have proved to be insufficient in terms of many ecosystem services compared to native species.

Native warm-season grasses are biologically different from cool-season grasses, providing some advantages as forage resources. Warm-season grasses (C_4 grasses) differ from cool-season grasses (C_3 grasses) in their chemical pathway for photosynthesis, allowing warm-season grasses to have higher photosynthetic potential than cool-season grasses in summer (Moser et al., 2004; Harper et al., 2007). Native warm-season grasses have higher optimum growth temperatures than common cool-season pasture grasses such as tall fescue, orchardgrass, and *Lolium perenne* L. (perennial ryegrass) and remain productive during hot summers when cool-season pasture grasses drop off substantially in productivity (George et al., 1992; Moser et al., 2004; Ball et al., 2007; Harper et al., 2007). Growth of NWSG species is optimal at temperatures ranging between 30° C and 35° C and drastically slows under 20° C (Anderson, 2000; Ball et al., 2007). Native warm-season grasses grow rapidly over a relatively short period of time while using water more efficiently and using less total water than cool-season grasses for biomass production (Harper et al., 2007). Warm-season, C_4 grasses require as little as one third the amount of water as cool-season, C_3 grasses (Moser et al., 2004). Further, several NWSG species can grow productively in lower fertility, marginal soils.

Current and Potential Uses of NWSGs in Forage Systems

Little bluestem, eastern gamagrass, big bluestem, indiangrass, and switchgrass have exhibited desirable qualities for use as forage resources (Keyser et al., 2011). Native warm-season grasses do not rely heavily on supplemental fertility to produce optimal yields, reducing fertilizer input requirements (Capel, 1991). Also, NWSGs process nitrogen more efficiently than cool-season alternatives, using half as much nitrogen to produce equal amounts of dry matter (Brejda, 2000; Moser et al., 2004; Tracy 2013). Native warm-season grasses have lower phosphorus tissue requirements, greater phosphorus use efficiency, and lower potassium requirements than cool-season grasses resulting in good growth even on deficient soils (Morris et al., 1982; Anderson, 2000; Brejda, 2000). Lime inputs are unnecessary for most NWSGs except in extremely low pH conditions under 5.0 (Capel, 1991; Keyser et al., 2011). Additionally, NWSGs are more efficient water users and use less total water than cool-season grasses (Anderson, 2000; Keyser, 2016). The C_4 photosynthetic pathway and deep root system of perennial NWSGs greatly increases water-use efficiency, conferring exceptional drought tolerance (Keyser et al., 2011; Tracy, 2013). Such benefits can improve agricultural sustainability while streamlining production by minimizing inputs.

Perhaps most important, the growth of NWSG species between roughly May and October, and most vigorous growth in June, July and August, allows them to provide high quality forage during the summer when many other common forage grasses become much less productive. Yields for NWSGs can be high with proper species selection and acceptable site conditions; in fact, 9000 to over 11,000 $kg \cdot ha^{-1}$ of forage harvested for hay is not uncommon

(Keyser et al., 2011). The extended lifespan of perennial species results in savings in seed, fertilizer, herbicide, and labor when compared to annual species. Under proper management, perennial NWSGs such as big bluestem, little bluestem, indiangrass, switchgrass and eastern gamagrass can persist longer than 20 years. These five NWSGs have exceptional forage production potential and are described in further detail below.

Switchgrass is a perennial NWSG from North American Prairies. It is well-known for its potential as a biofuel crop but is also an important species for forage production (Garten & Wullschleger, 1999). Palatability may decrease earlier than other NWSG forages because switchgrass develops stems several weeks earlier than other warm-season grasses. Improved varieties help mitigate this problem (Ball et al., 2007). The characteristic leafiness of upland varieties of switchgrass may be more advantageous for forage production than the more stemmy lowland varieties. However, lowland varieties are taller and produce more biomass than upland varieties which draws interest for biofuel production. Alamo, Kanlow, and Cave-in-Rock are among many varieties of switchgrass that exhibit high potential as forage crops (Capel, 1991; Keyser et al., 2011). Alamo is a lowland variety which thrives in wet soils and is capable of rapid, vigorous growth. Kanlow is another lowland variety well-suited to wet soils and has similar growth habits to Alamo, however seed dormancy rates are significantly higher. This can be mitigated simply with seed stratification to induce germination. Cave-in-Rock is an upland variety also with elevated seed dormancy rates but is not well adapted to wet soils and prefers well-drained upland soils (Keyser et al., 2011). Switchgrass varieties generally have stiff stalks which resist collapsing under snow cover and provide winter shelter for wildlife (Capel, 1991).

Figure 1: Switchgrass (Carolyn Fannon, Lady Bird Johnson Wildflower Center)

Big bluestem is another common perennial NWSG (Mitchell et al., 2005). Big bluestem provides excellent livestock benefits, producing quality forage during late spring and summer when there is a void in productivity of cool-season forages (Capel, 1991; Mitchell et al., 2005). Palatability and nutritive value remains over a longer period of time in big bluestem than switchgrass (Ball et al., 2007). Growth is slower than switchgrass, making management less demanding but also limiting crop yield below that of switchgrass (Keyser et al., 2011). Supplemental nitrogen can therefore benefit big bluestem stands (Capel, 1991; Ball et al., 2007). Drought tolerance of big bluestem is greater than other tall NWSGs (Anderson, 2000; Ball et al., 2007). OZ-70 and Rountree are two important varieties of big bluestem for forage production. OZ-70 is widely adaptable to a variety of sites, but somewhat less tolerant of waterlogged soils. Rountree has been on the market for years and performs well as a forage crop (Keyser et al., 2011). More recently, varieties such as Bonanza, Goldmine, Kaw, and Pawnee have been released (Vogel et al., 2006a; Vogel et al., 2006b). Big bluestem has weaker stalks and cannot remain upright under as much snow as other NWSG species (Capel, 1991).

Figure 2: Big bluestem (Charles W. Sexton, Lady Bird Johnson Wildflower Center)

Little bluestem is a smaller plant with lower yields which can be used collectively with other NWSGs to increase stand density, particularly in areas with poor quality soil (Keyser et al., 2011). Even more drought tolerant than big bluestem, little bluestem is easy to establish but does not produce substantial enough yields to stand alone as a summer forage (Anderson, 2000; Keyser et al., 2011). *Aldous* and *Ozark* are little bluestem varieties suited for forage systems (Keyser et al., 2011).

Figure 3: Little bluestem (Jerry Garrett, Lady Bird Johnson Wildflower Center)

Indiangrass is often combined with bluestem varieties in forage systems. Indiangrass prefers more well-drained soils and is heat and drought-tolerant (Ball et al., 2007). *Cheyenne*, *Rumsey* and *Osage* are notable varieties. Very high yields can be achieved with *Cheyenne* and possibly *Rumsey*, which is more resistant to rust (Capel, 1991; Keyser et al., 2011). *Osage* also has good forage potential and is a leafier and later-maturing variety (Capel, 1991; Keyser et al., 2011). Nutritive value is also greater than most other perennial warm-season grasses (Ball et al., 2007).

Figure 4: Indiangrass (Nan Hampton, Lady Bird Johnson Wildflower Center)

Eastern gamagrass is a longer-season NWSG with exceptionally high yields, however, little is planted due at least partially to difficulty in seed production and establishment (Ball et al., 2007; Keyser et al., 2011). Eastern gamagrass is exceptionally well-suited to wetter soils and may be ideal for wetter areas of a field which are less favorable for other species (Ball et al., 2007). *Pete* and *Highlander* are varieties which are productive and appropriate for the Mid-South region. *Highlander* generally produces higher quantities of forage than *Pete*, which is the more traditional variety available (Keyser et al., 2011).

Figure 5: Eastern gamagrass (Carolyn Gannon, Lady Bird Johnson Wildflower Center)

Diseases and Pests

Diseases

Limited information is available on pest and disease issues associated with NWSGs. Pest and disease information on switchgrass is more readily available than big bluestem, little bluestem, indiangrass, or eastern gamagrass. This may be a function of the relative ease of establishing switchgrass, thus they may be more commonly planted and studied. Even though many diseases have been reported on switchgrass, their potential to cause severe damage is largely unknown. According to Mitchell et al. (2008), switchgrass and other NWSGs have been predisposed over time to native fungi, bacteria, and microbes, and this exposure possibly has conferred some level of disease resistance. Such natural levels of disease resistance may be one reason why it is difficult to measure significant reductions in the productivity of NWSG stands that exhibit disease. Disease problems with exotic cool-season forage grasses, such as rust and leafspot in orchardgrass and foliar diseases in smooth brome can cause significant problems (Ball et al., 2007). Some diseases of concern include switchgrass rust caused by *Puccinia spp*. and *Uromyces graminicola*, anthracnose (*Colletotrichum navitas*), smut (*Tilletia maclaganii*), sharp eye spot (*Phyzotonia cerealis*), helminthosporium spot blotch (*Bipolaris sorokiniana*), and viral disease caused by Panicum mosaic virus (PMV), Phoma leaf spot (*Phoma spp*.), and Fusarium root rot (*Fusarium spp*.) (Ramachar & Cummins, 1965; Moser et al. 2004; Crouch et al. 2009; Mitchell et al. 2014). Available research on NWSG diseases is summarized below.

In a 1999 disease survey in Iowa, switchgrass smut occurred in 100% of fields studied and greatly reduced biomass of infected plants (Gravert & Munkvold, 2002). Thomsen et al. (2008) studied switchgrass smut in Iowa and observed that smut incidence is linearly related to yield loss, which is consistent with the biomass reduction observed by Gravert and Munkvold (2002). Switchgrass smut is caused by the fungal pathogen *Tilletia maclangi*. Other fungi species, including *Claviceps purpurea* and *Sphacelotheca occidentalis*, cause smut in big bluestem (Tiffany & Knaphus 2004). Gravert and Munkvold (2002) also observed switchgrass anthracnose in 88% of fields studied, however, significant damage was not observed. Crouch et al. (2009), found *Colletotrichum caudatum*, a common fungus on big bluestem and indiangrass, present on anthracnose infected switchgrass; however, it could not be determined if *C. caudatum* was pathogenic because the sample also contained a small number of *C. navitas* spores, a known pathogen of switchgrass. Several other anthracnose causing species, such as *Phyllachora luteomaculata*, *Colletotrichum graminicola*, and *Phyllachora griminis* have been reported on switchgrass (Tiffany & Knaphus 2004). The extent of biomass production limitation due to switchgrass anthracnose has not been confirmed (Crouch et al. 2009). According to Tiffany & Knaphus (2004), *P. luteomaculata* and *C. graminicola* also have been reported on little bluestem and both little bluestem and big bluestem, respectively.

Leaf spot of switchgrass (caused by *Bipolaris oryzae*), a potentially pathogenic fungi, has been observed in Mississippi, North Dakota, New York, and Tennessee (Krupinsky et al. 2004;

Tomaso-Peterson et al. 2010; Waxman et al. 2011; Vu et al. 2013). Tiffany and Knaphus (2004) reported that *Elisinoë panici and Pseudoseptoria donacis* also cause leaf spot on switchgrass. Leaf spot on big bluestem and little bluestem can be due to *Ascochyta brachypodil* or *Stagonospora simplicior*, while *Septoria andropogonis* and *Mycosphaerella sp.* infect big bluestem alone (Tiffany and Knaphus 2004). *Phyllosicta sp.*, *E. panici* and *S. simplicior* reportedly cause leaf spot on indiangrass (Tiffany and Knaphus 2004).

Rust incidence due to individual rust species has been notably variable from year to year, and therefore it may be difficult to predict and document possible outbreaks (Tiffany & Knaphus, 1984). However, rust fungi can cause severe economic damage, especially in monocultures, due to their tendency to attack fresh tissue of healthy and vigorous plants (Cummins & Hiratsuka, 2003). Gustafson et al. (2003) observed that typically only one cultivar of switchgrass is grown in an area, and suggested that to improve disease resistance, the most resistant individuals within the best families for a particular climate should be selected. Rust species often spread northward via wind in a stepwise-fashion due to overwinter survival or spores in the southern part of its distribution (Kenaley et al. 2016). Numerous rust species have been reported on NWSGs. Gravert and Munkvold (2002) studied various fields in Iowa and observed switchgrass rust in almost half of fields. Since then, switchgrass rust has been reported in Alabama, Arkansas, Colorado, Kansas, Oklahoma, Nebraska, Tennessee, Virginia, and New York (Ramachar & Cummins, 1965; Tiffany & Knaphus, 1984; Uppalapati et al., 2013; Zale et al. 2008; Hirsch et al. 2010; Frazier et al. 2013; Kenaley et al. 2016). Lesions caused by switchgrass rust observed at several locations in Arkansas covered between 25% and almost 100% of total leaf tissue (Hirsch et al. 2010). This finding is consistent conclusions by Zale et al. (2008) who observed switchgrass rust in a variety of cultivars in Tennessee and stated that some cultivars were highly susceptible and reduction in total biomass due to switchgrass rust is likely. In general, lowland switchgrass cultivars are more resistant to the rust pathogens while upland cultivars are usually more susceptible (Lamp et al. 2007; Frazier et al. 2013; Uppalapti et al., 2013). Most reports found that switchgrass rust was caused by *P. emaculata* (Ramachar & Cummins, 1965; Tiffany & Knaphus, 1984; Zale et al., 2008; Hirsch et al., 2010; Frazier et al. 2013; Kenaley et al. 2016), however, *Uromyces graminicola* and *Puccinia graminis* have also been noted (Tiffany & Knaphus, 1984; Tiffany & Knaphus 2004; Lamp et al. 2007, Kenaley et al. 2016). Damage due to rust may be mainly associated with *P. emaculata*, which has been observed on switchgrass in Alabama and Arkansas where U. *graminicola* has not yet been reported (Kenaley et al. 2016). Rust species have also been observed on big bluestem, little bluestem, and indiangrass. *Puccinia andropogonis* and *Sphaerellopsis filum* are rust species which affect big bluestem and little bluestem, while *Puccinia ellisana* affects only little bluestem and *Uromyces andropogonis* affects only big bluestem (Tiffany & Knaphus, 1984, Tiffany & Knaphus, 2004). Indiangrass rust can be caused by *Puccinia virgata* (Tiffany & Knaphus, 2004).

According to Moser et al. (2004), diseases are not common with NWSGs and typically pastures can recover readily from disease. Increases in soil microbial diversity and activity associated with healthy perennial grass stands confer greater capability of suppressing soil-borne diseases (Cox et al. 2005). For example, evidence suggests that grassland soils suppress *Rhizoctonia solani* AG3 (root rot), reduce effects of *Gaeumannomyces graminis* var. *tritici* (takeall disease), and may suppress diseases caused by root pathogens (Clapperton et al., 2001; Van Eslas et al., 2002; Neher, 1995). With respect to NWSGs, switchgrass rust, caused by *P. emaculata*, can seriously limit switchgrass yield and quality and currently may be the most concerning disease problem. Periodic burning can eliminate fungal inoculum, however, fungi can reestablish extremely quickly, in as little as 2 years (Tiffany and Knaphus, 2004). Species selection is also important in reducing disease incidence. For example, Stuteville et al. (2001) suggested that the switchgrass cultivar ‘Kanlow’ may be resistant to smut, although it is a lowland type and would not be suitable for large scale planting in the northern and central United States. Further, mixing species and cultivars will mitigate disease outbreaks by lowering selection pressure and creating natural barriers to disease spread.

Further research efforts should focus on developing cultivars with pest and disease resistance and refining cultural and biological control methods (Stewart & Cromey, 2011). Currently, disease is not a major issue in NWSG plantings, especially in terms of associated damage. Smut is probably the most damaging NWSG disease, primarily switchgrass smut, and should be monitored. Rust diseases should also be of concern due to their tendency to attack healthy, vigorous plants and unpredictability of outbreaks.

Insect Pests

Insect pests may also reduce the productivity of NWSG stands (Mitchell et al. 2014). Although this has not been directly studied, some pest pressure below an economic threshold may help reduce excessive vigor and delay maturity. Mielke (1993) stated that pest problems are minor with native species and typically are not season-long epidemics. Similarly, Ball et al., (2007) reports that pests are usually not a problem with big bluestem, eastern gamagrass, indiangrass and switchgrass. However, Prasifka et al. (2010) suggest that insect pests of perennial grasses, particularly switchgrass, may be present but not yet identified. For example, a previously unidentified stem boring caterpillar (*Blastobasis repartella* Dietz) was observed in switchgrass stands located in Illinois, Iowa, Nebraska, Wisconson, Michigan, South Dakota, and North Dakota (Prasifka et al., 2010). Similarly, Boe and Gagné (2010) identified a new species of gall midge (*Chilophaga virgate* Gagné) on switchgrass tillers in South Dakota and observed that infested tillers exhibited greatly decreased mass and practically no viable seed production. Also, grasshoppers (*Orthoptera*) may threaten switchgrass biomass productivity, as they are well-known as an herbage feeding insect (Moser et al. 2004). Grasshoppers are also common pests of cool-season grass pastures, however, degree of injury by most forage grass insect pests is not well documented (Moser & Hoveland, 1996). Additionally, Ball et al. (2007) reports that armyworms may cause damage to orchardgrass and smooth brome.

Chemical control of insect pests is not economical with many pasture grasses (Moser & Hoveland, 1996). Instead other approaches may be used to reduce insect pest populations. For example, planting of non-crop vegetation, particularly herbaceous species, on crop land increases biodiversity, enhances ecosystem services, and impacts predation of crop pests by natural enemies (Bianchi et al. 2006, Landis et al. 2000, Werling et al. 2012). Native warm-season grasses provide habitat for pollinators and insects while forbs can be integrated to provide nectar sources. A variety of natural predators of insect pests use non-crop habitats, such as NWSG habitats, for nectar and hibernation (Bianchi et al. 2006). Other cultural practices include use of resistant genetics, crop sanitation and rotation, biological control, and grazing and harvesting management (Moser & Hoveland, 1996).

Weeds and Weed Management

Weed competition can greatly limit NWSG establishment, in some cases, causing complete stand failure (Martin et al., 1982; Mitchell & Britton, 2000). Weed control is critical and should begin well before planting, especially with NWSGs, which are usually slower and more difficult to establish than exotic cool-season grasses (Ball et al., 2007). It is important to use high quality certified seed and minimize the potential of planting weed seeds with forage seeds. A variety of herbicide chemistries have been tested for effectiveness in controlling weeds during and after establishment of NWSGs. Metolachlor applied at planting is more effective than atrazine at controlling warm-season annual grasses, including *Digitaria sanguinalis* (crabgrass), *Panisum dichotomiflorum* (fall panicum), *Setaria viridis* (green foxtail), *Setaria glauca* (yellow foxtail), and *Echinochloa crusgalli* (barnyardgrass) (Mitchell & Britton, 2000). Big bluestem is metolachlor tolerant and switchgrass is tolerant when treated with napthalic anhydride, a seed protectant (Griffin et al., 1988). Warm-season annual grasses and exotic warm-season grasses may be more of a significant threat to NWSG establishment than cool-season grasses because they are actively growing and competing for resources at the same time. While NWSGs are dormant, glyphosate can be used to target cool-season invaders which are active and susceptible (Mitchell & Britton, 2000). Imadazolinone herbicides have been successfully used with big bluestem, switchgrass, little bluestem, and several native forbs to improve stand establishment in native warm-season grass revegetation (Masters et al., 1996). Bermudagrass, a common exotic forage, can be extremely difficult to manage. Currently, imazapyr by itself or in combination with glyphosate are the most effective options for controlling bermudagrass as a part of pasture renovation (Ferrell et al., 2005).

Weed competition is a major limiting factor in the establishment of NWSGs. Herbicides are a valuable tool during the problematic establishment period and may accelerate NWSG establishment, so they can be competitive with invaders. Native warm-season grasses vary in susceptibility and tolerance of certain herbicides, so herbicide application decisions should be carefully considered based on present and desired forage species. Once established, management may shift to a more integrated approach including cultural and biological control to continue promoting NWSGs and herbicide use may taper off.

ECOSYSTEM SERVICES

Definition

Ecosystem services are provided by properly functioning ecosystems and are directly valuable to humans. Ecosystem services can be divided into four main categories including supporting, provisioning, regulating, and cultural services (Farber et al., 2006; Palm, 2014; Toledo et al., 2014). Nutrient cycling, soil formation, net primary production, wildlife habitat structure and size, pollination, seed dispersal, and the hydrological cycle are further divisions of supporting ecosystem services, the underlying processes that sustain ecosystems (Farber et al., 2006). Cultural ecosystem services are non-material benefits that contribute to development and cultural advancement of people including aesthetics, recreation, management practices, and cultural ties to the land (Toledo et al., 2014). Provisioning services benefit humans as natural resources and raw materials, such as the provision of food, drinking water, timber, wood and fiber, fuel, medicinal resources and genetic resources (Millennium Ecosystem Assessment, 2005; Farber et al., 2006). Regulating services make life possible through ecosystem processes that moderate natural phenomena. Nutrient regulation, soil retention, biological regulation, decomposition, water purification, flood regulation, carbon storage and climate regulation are regulating services (Millennium Ecosystem Assessment, 2005). Human activity has profoundly influenced ecosystems and associated services, perhaps most alarmingly the biogeochemical cycles that support life (White et al., 2000).

Relationship to Forage and Cropping Systems

Agricultural systems are dependent on ecosystem services to support critical functions of production. Conversely, agricultural systems provide certain ecosystem services of both agricultural and non-agricultural nature. Many ecosystem services are being degraded due to human influence. Dramatic growth in food, water, timber, fiber, and fuel demand has necessitated most of the changes that have been made to ecosystems. The provisioning of each of the four main categories of ecosystem services is variable based on soils, vegetation, climate, and ecological processes. Some regulating and provisioning ecosystem services such as water quality regulation, pollination, erosion control, carbon storage and climate regulation are commonly reduced by agricultural intensification. Loss of biodiversity and wildlife habitat, nutrient runoff, sedimentation and erosion, pesticide poisoning, and greenhouse gas emissions can be direct products of cultivation and grazing. Meanwhile, provisional ecosystem services such as food for a growing population, fiber, and bioenergy are increased by intensive agriculture (Palm, 2014). Ecosystem-services based management involves the modification of ecosystems in order to alter services due to ecosystem structures and processes (Farber et al., 2006). Changes in local land use and cover, species introduction or removal, technology adaptation and use, harvest and resource consumption, and external inputs such as fertilizer, pest management, and irrigation are drivers of change associated with agriculture which can be managed to maximize ecosystem services (Millennium Ecosystem Assessment, 2005). Specific ecosystem services which may be related to the establishment of NWSGs are evaluated in detail below.

NATIVE WARM-SEASON GRASSES AND POTENTIAL ECOSYSTEM SERVICES

Crop and Livestock Production

Livestock production is an important service resulting from healthy, well-managed rangelands and pastures. Rangelands are typically dominated by native vegetation such as grasses, forbs, and shrubs which are suitable for grazing; some have been seeded to perennial native or introduced species. On the other hand, pasture is typically a community of introduced forage species (Sprague, 1974). In general, forage systems are managed based on the primary goal of livestock production, however, production objectives can be met with conservation as a guiding principle (Fuhlendorf et al., 2012). Frequent use of cool-season grasses as forage, resulting in summer forage shortages, has developed a need for alternative forage resources (Temu et al., 2014). As an alternative to using solely cool-season grasses in a forage system, NWSG fields can be used to complement cool-season fields when forage is scarce during the summer (Jung et al., 1985; Anderson, 2000; Giuliano & Daves, 2002; Keyser et al., 2011). During this time, NWSGs can provide excellent benefits to crop and livestock production.

Native warm-season grasses utilized in forage production can improve summer herbage production during lag periods of cool-season grasses (Robins, 2016). Over 60 percent of cool-season grass annual growth occurs before June, while between 60 and 90 percent of that of NWSGs occurs between June and August (Anderson, 2000). Steers grazing on cool-season grasses in the spring and fall and warm-season grasses in the summer have significantly higher average daily gains than those grazing on cool-season grasses all season (Anderson, 2000). Figure 6 shown below illustrates the void in cool-season grass production filled using NWSGs.

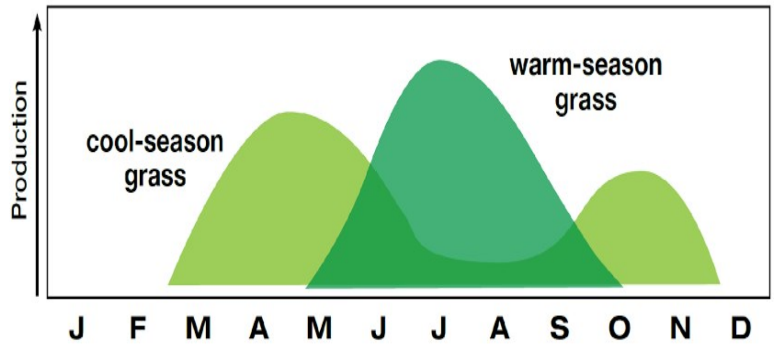

Figure 6: Comparison in production of warm-season and cool-season grasses by month (Keyser et al., 2011)

While cool-season grasses still have somewhat higher quality than NWSGs during the summer, they substantially drop in biomass during this time (Robins, 2016). Native warm-season grasses are capable of producing significantly more biomass during the summer than cool-season alternatives, particularly with less precipitation (Tracy et al., 2010; Robins, 2010; Robins, 2016). Native warm-season grasses can produce 1000 to 2000 kg·ha^{-1} more biomass than cool-season varieties during the summer (Robins, 2010; Tracy et al., 2010). Switchgrass and big bluestem consistently produce summer biomass among the highest levels of any NWSG species (Robins, 2010).

Forage Quality

According to Wedin and Fales (2009), there are three components of forage quality: intake (how much animals will eat), nutritive value (the nutrient content of the forage), and antiquity factors (such as presence of toxins or undesirable morphological features). Forage nutritive value and intake are impacted by factors including crude protein (CP) concentration, leaf-to-stem ratio (LSR), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). Neutral detergent fiber is a measurement of total cell-wall constituents in a plant (hemicellulose, cellulose, lignin, and insoluble ash) while ADF is similar but excludes hemicelluloses (Abaye et al., 2009). Crude protein is a measure of nitrogen in forage while digestibility refers to the proportion of the forage absorbed during digestion (Allen et al., 2011). Crude protein concentration and digestibility increase with leafiness, which can be used as an indicator of forage nutritive value. *In vitro* dry matter digestibility (IVDMD) is a measurement estimating the extent forage will be absorbed as it is digested by an animal (Abaye et al., 2009). Toward maturity, the cell walls of NWSGs lignify and leafiness tends to decline resulting in above optimal ADF and ADL and suboptimal CP, IVDMD, and overall nutritive quality (Jung et al., 1985; Moser et al., 2004; Wedin & Fales, 2009; Temu et al., 2014). Environmental factors also impact NWSG nutritive value late in the season. As temperature increases, forage nutritional value tends to decrease (Moser et al., 2004). Photoperiod changes late in the season and triggers the reproductive phase of NWSGs, reducing their nutritional value as the grasses mature and lignify (Temu et al., 2014). Crude protein, water soluble carbohydrates, and biomass vary depending on interactions between the variety of grass and the environment it is grown in.

Crude protein measurement is not necessarily equivalent with CP digestibility or quality (Allen et al., 2011). Much of the protein in NWSGs can be found in slowly degraded bundle sheath cells. Some of these proteins escape rumen degradation, explaining occasional deficiencies in Degradable Intake Protein (DIP), a subdivision of CP, in NWSG based diets (Anderson, 2000; Moser et al., 2004). Many NWSG species respond well to nitrogen fertilization and studies show that nitrogen fertilization in NWSG pastures could improve rumen fermentation, increase CP concentration, and increase intake of warm-season forages by steers (Anderson, 2000; Moser et al., 2004). Nitrogen fertilization has resulted in observed increases in CP concentration in indiangrass, big bluestem, eastern gamagrass, and switchgrass (Waramit et al., 2012). Nitrogen fertilization of switchgrass, big bluestem, and indiangrass results in increases of DIP, thus also increasing CP (Anderson, 2000). However, NWSGs already mature rapidly and nitrogen fertilization may increase the complexity of management. In such cases, harvesting of NWSGs should occur before mid-July, as past this point NDF increases beyond levels for acceptable quality forage (Waramit et al., 2012). Maturity at harvest is the main factor influencing forage quality (CP, NDF, and IVDMD) of NWSGs (Waramit et al., 2012). Early season grazing and mowing can mitigate losses in forage quality due to maturity by keeping plants vegetative, which improves livestock production by reducing fiber concentration (Bonin & Tracy, 2011). While it has been established that IVDMD of NWSGs is lower overall than cool-season grasses, it is important that the timing of peak IVDMD of NWSGs is different than that of cool-season grasses. Griffin et al. (1980) observed that IVDMD estimates of big bluestem and switchgrass were on average over 9% higher than that of tall fescue when both were harvested in mid-July. Further, Reid et al. (1988) that warm-season grass intake, and subsequently animal performance, is higher than anticipated from IVDMD and fiber concentrations.

It is well known that NWSGs as a group produce lower quality forage than cool-season grasses. Cool-season grasses as a group contain more CP, lower NDF, and higher IVDMD levels than NWSGs (Griffin et al., 1980; Morris et al., 1982; Anderson, 2000; Moser et al., 2004; Robins, 2016). However, during ruminant digestion, NWSGs may not be digested by the rumen and then can be absorbed through the intestines, possibly improving their quality (Keyser et al., 2011). Although CP concentration tends to decline as NWSGs reach maturity, CP concentration in NWSGs can be acceptable for forages when harvested at shorter intervals early in the season (Temu et al., 2014). Varieties of NWSG species can be bred for increased forage yield and IVDMD, improving livestock performance (Mitchell et al., 2005). A study in California showed that little bluestem and switchgrass can obtain similar CP concentrations as cool-season grasses such as orchardgrass and tall fescue under supplemental irrigation (George et al., 1992). Nutritive quality is also enhanced in NWSGs harvested early and under shorter intervals of 30 to 60 days (Temu et al., 2014). Hudson (2010) reported no clear benefit of including switchgrass or big bluestem in cool-season pastures, but sequentially grazed after cool-season grasses had declined and NWSGs were lignified and overly mature. Rotating a NWSG pasture in sequence with cool-season pastures can relieve cool-season pastures during the summer when productivity is limited (Moore et al., 2004). Thus, for a certain period, NWSGs can serve as a valuable nutritive resource while other sources may be scarce. However, past a certain threshold, elevated NDF concentrations will result in daily animal intake too low to provide adequate energy for the animal; this may impede livestock grazing on NWSGs alone (Bonin & Tracy, 2011). When compared to NWSGs alone, the inclusion of native forbs and legumes can increase CP concentration and IVDMD while lowering NDF and ADF (Posler et al., 1993; Bonin & Tracy, 2011). Additionally, forage legumes produce high protein and high mineral forage while eliminating need for nitrogen fertilization by capturing nitrogen through the air (Wedin & Fales, 2009).

A study by Kurve et al. (2015) revealed that cattle fed NWSGs in the stocker phase and tall fescue to finish can produce high quality beef. Three summer forage treatments including bermudagrass, indiangrass, and a NWSG mixture of indiangrass, big bluestem, and little bluestem were grazed by Angus, Hereford, and Charolais crossbred steers. Several indicators of meat quality, including color, pH, and instrumental tenderness, did not vary between the three treatments. Indiangrass fed cattle had less cooking loss and a greater percentage of Select grade carcasses when compared to the NWSG mix or bermudagrass. Consumer ratings of all three treatments indicated that beef cattle fed NWSGs during the stocker phase was acceptable.

Wildlife

In the United States, extensive natural grasslands consisting primarily of NWSGs once provided basic habitat requirements to over 800 species of native wildlife and plants (Ryan & Marks, 2005). Native warm-season grasses provide important habitat for native wildlife while common exotic forage species do not have the structure, cover, and growth habit to provide such habitat value (Ryan & Marks, 2005; Keyser et al., 2011). Exotic plants are those which are not native to the area where it is found. Many forage species are considered naturalized because they naturally reproduce in an area from which they are not native, but do not necessarily invade native plant ecosystems. Not all naturalized plants are invasive plants, which grow rapidly and disrupt ecosystems. Invasive plant species frequently reduce habitat quality for native wildlife species, many of which are not adapted to exotic plant monocultures.

Birds

Many species of grassland birds have been negatively impacted by the conversion of native grasslands to naturalized forage grasses and plowed croplands in the early 19th century (Monroe et al., 2016). Reintroducing NWSGs as a part of forage systems may provide cover for grassland birds. Grassland birds such as *Spiza americana* (dickcissel), and *Sturnella magna* (eastern meadowlark) and upland birds including *Meleagris gallopavo* (wild turkey), *Phasianus colchicus* (ring-necked pheasant), and *Colinus virginianus* (northern bobwhite) thrive in native grasslands because of the cover provided by their diverse structure, protection from predators, and the availability of food such as fallen seed and invertebrates (Ryan & Marks, 2005; Temu et al., 2011; Adams et al., 2013). Fletcher and Koford (2002) suggest that restored grasslands can be just as effective as habitat for many native grassland bird species as native prairie, noting that species richness and overall densities of grassland bird species were very similar in both. In fact, bird populations may increase tenfold in some places when only 5% of hayfields are converted to warm-season grasses (Ryan & Marks, 2005). Obligate grassland species, such as *Tympanuchus cupido* (greater prairie chicken), may particularly benefit from conversion of pasture and hayfields to NWSGs because they require large tracts of unbroken habitat and there is a limited area of publicly owned land available for conservation (McNew et al., 2015). Thus, NWSG establishment in forage systems has the potential to benefit certain species of native birds while also having value for beef production in the summer months (Monroe et al., 2016).

Using NWSGs in forage systems can conserve species of native grassland birds due to physiology and structural characteristics such as greater height and bunching growth habit which are more favorable for habitat when compared with cool-season alternatives. Greer et al. (2016) found that several species of grassland birds, *Calcarius ornatus* (chestnut-collared longspur), *Calamospiza malanocorys* (lark bunting), *Ammodramus savannarum* (grasshopper sparrow), and *Sturnella neglecta* (western meadowlark), were negatively affected by increases in percent cover of introduced plant species in central and western South Dakota. Specifically, high percentages of introduced grass species may be detrimental to occurrence of western meadowlarks and lark buntings (Greer et al., 2016). The structure and cover of vegetation is probably more important to many grassland bird species than the species composition of the grassland (Monroe et al., 2016; Monroe et al., 2017). Height of vegetation is important in providing cover and an open structure helps to facilitate movement of birds and other wildlife. Native warm-season grasses can improve cover throughout the nesting season of grassland birds because they produce 70% of their biomass after June 1st, whereas cool-season grasses produce most of their biomass before. Delaying mowing and grazing until after the critical nesting period of most grassland birds is beneficial. Tall and dense vegetation is preferred for nesting of dickcissels and nest density and polygyny rates are higher in such vegetation (Monroe et al., 2016). Tall growth of NWSGs camouflages nests from predators and stabilizes the microclimate around the nest. Height, structure, and vegetative cover are also critical for nesting ducks, particularly *Anas platyrhynchos* (mallard) and *Anas acuta* (northern pintail), which favor tall vegetation with abundant cover (Farigone et al., 2009). Commonly planted bermudagrass and tall fescue grow denser, shorter, and more uniform than NWSGs, resulting in poor nesting resources, food resources, and minimized facilitation of movement for grassland birds (Ryan & Marks, 2005; Barnes et al., 2013). Bermudagrass is low-growing, forming stolons as it spreads and lacking suitability for dickcissel nesting, in particular. Despite grazing practices, bermudagrass has less than half the height growth potential of NWSGs such as indiangrass and big bluestem (Monroe et al., 2016). Overall, exotic pastures managed for consistency in structure and composition renders them inoperative for many native bird species (Fuhlendorf & Engle, 2001; Monroe et al., 2016; Monroe et al., 2017). Proper management of NWSGs in forage systems can provide benefits to tall-structure specialists and other grassland bird species without sacrificing production goals (Monroe et al., 2016).

Grassland birds requiring short sparse vegetation, including grasshopper sparrow and *Passerculus sandwichensis* (Savannah sparrow), probably favor more intensively harvested or grazed grasslands, while *Cistothorus platensis* (sedge wren), Henslow's sparrow, *Spinus tristis* (goldfinch), *Geothlypis trichas* (common yellowthroat), dickcissel and *Ammodramus leconteii* (LeConte's sparrow) would be negatively impacted by recent disturbance or shorter vegetation (Fletcher & Koford, 2002; Farigone et al., 2009; Rahmig et al., 2009; Ribic et al., 2009; Hovick et al., 2014). In fact, grasshopper sparrows and savannah sparrows may prefer restored grasslands when compared to native prairies because of lower total vegetation cover (Fletcher & Koford, 2002). Several native bird species, including *Ammodramus* bairdii (Baird's Sparrow), *Charadrius monanus* (Mountain Plover), and *Calcarius ornatus* (Chestnut-collared Longspur) are common in grazed prairies and likely evolved with large grazing animals (Fuhlendorf & Engle, 2001). While many grassland bird species thrive in maintained NWSG fields, dickcissel, a native grassland bird species under conservation concern, prefer less intensively managed, denser habitat structure (Rahmig et al., 2009).

Giuliano and Daves (2002) found in a study in Pennsylvania that avian abundance and species richness were both 1.6 times greater in actively managed beef production fields planted with native warm-season grasses (switchgrass and big bluestem) than cool-season pastures (orchardgrass mixed with *Trifolium pretense*, red clover). Several species including *Melospiza melodia* (song sparrow), *Spizella pussila* (field sparrow), *Turdus migratorius* (American robin), *Spizella passerina* (chipping sparrow), grasshopper sparrow, and *Geothlypis trichas* (common yellowthroat) were found more often in warm-season grass fields. Species such as *Pooccetes gramineus* (vesper sparrow), mallard, *Spizella arborea* (American tree sparrow), *Empidonax* sp. (Empidonax flycatcher) were found exclusively in warm-season grass fields.

Native warm-season grasses may also provide a more suitable nesting habitat for many bird species. A study in Mississippi observing dickcissel showed greater nest density and productivity in a NWSG polyculture of indiangrass, little bluestem, and big bluestem than exotic forage systems (Monroe et al. 2016). This finding is consistent with studies from Nebraska and Iowa showing greater avian nest density and success in NWSG pastures of switchgrass and big bluestem than exotic pastures of alfalfa and orchardgrass (George et al., 1979; Capel, 1991). Nest success of dickcissel and grasshopper sparrow have been observed to be between 100% and 350% greater in NWSG hayfields than other managed grasslands (Rahmig et al., 2009). Native warm-season grasses are harvested after the critical nesting period of many birds, which explains, in part, the increases in nest success. Furthermore, Giuliano & Daves (2002) found that overall nest success and fledge rates of bird species was 30% and 80% greater, respectively, in warm-season fields consisting of switchgrass and big bluestem than cool-season fields of mainly orchardgrass.

In addition to protective cover, the structure of NWSG stands allow birds to move more efficiently through grasslands (Capel, 1991; Ryan & Marks, 2005). In fact, grazing of NWSGs maintains this openness and may actually be necessary for adequate habitat of species such as the northern bobwhite and grasshopper sparrow (Harper et al., 2015). West et al. (2016) found that establishment of NWSGs (big bluestem, indiangrass, switchgrass, little bluestem, and/or eastern gamagrass) in forage production systems provides adequate habitat for occupancy by eastern meadowlark, field sparrow, grasshopper sparrow, northern bobwhite, and red-winged blackbird under a variety of management regimes. Dickcissel, eastern meadowlark, and grasshopper sparrow survival and nest density as well as overall bird species diversity were unaffected by varying grazing systems on NWSGs in a study in Oklahoma and Kansas (Rahmig et al., 2009). Similarly, Harper et al. (2015) observed suitable vegetation height and density for nesting and brooding of grassland songbirds and northern bobwhites in full-season (May to August) and early-season (30 days beginning in May) grazing of NWSG forage treatments including a mixture of big bluestem and indiangrass, switchgrass, and eastern gamagrass.

The grazing height of NWSG stands must be managed to favor grassland bird species. Management regimes that maintain NWSGs canopy height between 30 to 60 cm are recommended for northern bobwhite habitat and greater prairie chicken nesting habitat (Harper et al., 2015; McNew et al., 2015). Proper management of NWSGs limits mowing and grazing to no less than 20 to 30 cm (Giuliano & Daves, 2002). This is much higher than the 10 to 15 cm minimum recommended to protect other wildlife species such as amphibians, reptiles, and invertebrates. Cool-season pastures are typically grazed or mowed much lower, often less than 5 cm. However, grazing and haying management regimes of NWSGs would not differ greatly from normal proper management of NWSGs to incorporate grassland bird conservation benefits.

Possibly the most significant benefit for grassland birds of NWSG pastures and hayfields when compared to cool-season grass alternatives is the timing of their productivity which results in grazing or harvest after critical nesting periods of birds. Fletcher and Koford (2002) reported high densities of grassland birds in restored grasslands, despite post-breeding season mowing. However, individual grassland bird species differ significantly in requirements for optimal habitat. During harvesting periods, a strip of untouched NWSGs bordering woody cover, fence lines, and drainage passageways may provide adequate cover for some species (Capel, 1991). Ideally, a harvest technique leaving a mixture of harvested and unharvested NWSG patches would favor a wide range of bird species. Certain burn regimes that focus grazing on recently burned patches while leaving some unburned patches may be effective in promoting biodiversity (Hovick et al., 2014; McNew et al., 2015). Incorporation of NWSGs in exotic forage systems while managing haying, grazing, and burn regimes to encourage a diversity of vegetation height and structure is likely the most ideal solution to benefit overall avian biodiversity (Fuhlendorf et al., 2006; Monroe et al., 2016).

Prescribed Fire and Grassland Bird Habitat

Prescribed fire benefits NWSG stands by creating open ground for wildlife movement, removing excessive litter, enhancing structural diversity, recycling nutrients in standing dead vegetation, and controlling cool-season grass, invasive species, and woody plant invasion (Capel, 1991; Millenbah et al., 1996; Adams et al., 2013). Such benefits are not achieved when implementing prescribed burns on cool-season forage grasses such as tall fescue, which greatly limits the rate of spread of the fire due to excessive moisture (McGranahan, 2012). Rahmig et al. (2009) found greater avian diversity in grazed NWSG pastures and hayfields, particularly those implementing prescribed burns, than undisturbed fields of the same species due to more biomass, litter, dead grass cover, and forb cover in undisturbed fields. Essentially all species of grassland birds re-nest following nest losses due to burning (Moser et al., 2004). Fire ensures appropriate structure and height of vegetation for avian nesting habitat and has been observed to particularly benefit dickcissel and *Agelaius phoeniceus* (red-winged blackbird) nest abundance and productivity (Adams et al., 2013; Monroe et al., 2016). Adams et al. (2013) observed that nest density in a big bluestem, little bluestem, indiangrass, and forb mix was greater when managed through periodic burns than disking. Excessive damage to root structures due to disking could result in longer recovery times of grass stands, consequentially limiting grassland bird nesting for a longer period of time (Harper et al., 2007). However, prescribed fire may limit grassland bird nesting with poor timing of the burn. A prescribed burn in April will avoid disturbance during nesting of many grassland birds, although it seems that periodic burns to not directly kill mature birds (Erwin & Stasiak, 1979; George et al., 1979; Capel 1991).

Reptiles, Amphibians and Mammals

There is a lack of research on the effects of agricultural practices and pasture grasses on reptiles. However, early-successional habitats, including agricultural fields, provide foraging and nesting resource areas for *Glyptemys insculpta* (North American wood turtle), *Terrapene Carolina carolina* (Eastern box turtle), and likely other species (Erb & Jones, 2011). Also, Kaufman (1992) found that wood turtles spend more time during their active season in creek habitat than any terrestrial habitat, although grass-sedge-forb association accounted for much of their time on land, especially for female turtles. This indicates that grass habitat is important for certain reptile species, including wood turtles. Saumure et al. (2007) studied the effects of haying and agricultural activities on wood turtles over 2 years and reported that 20% of the 30 turtles observed died as a result of harvesting activity, another 27% were injured, and none died of natural causes. It can be assumed that other reptile species of similar size, regardless of geographic location, will exhibit similar fatality rates. According to Humbert et al. (2009), one study has focused on the relationship between grass harvesting and wildlife body size, reporting that smaller individuals are less vulnerable than larger ones, likely due to blade height. On the other hand, Saumure et al. (2007) noted higher mortality rates in juvenile wood turtles when compared to adults but concluded that this may be due to fully ossified carapaces of adults that may aid in surviving an injury rather than death despite larger body size than juveniles. Also, some wood turtle fatalities were the result of burying from erosion, rather than direct encounters with mowing or other harvesting equipment (Saumure et al., 2007). Juvenile wood turtles frequently relocate to hayfield banks, where they can be buried by severe erosion or dredging to stabilize banks (Tuttle & Carroll, 2005). Reptiles located in bank habitats would benefit from NWSGs, which are excellent for mitigation of erosion and bank stabilization. Cutting grasses at height of 10 cm or greater is recommended for reducing turtle mortality, and may also increase yield, reduce erosion, and decrease wear on machinery (Saumure et al., 2007). Similarly, Erb and Jones (2011), suggest that mower blade height, if higher than 15 cm, does not impact turtle mortality rates. Cutting height could likely be lowered for the second harvest as turtles will naturally flee toward banks before the second harvest (Saumure et al., 2007). However, mortality can also occur due to crushing by equipment tires, regardless of cutting height (Erb & Jones, 2011).

A few studies have focused on the impacts of hay harvesting on amphibians, possibly due to concerns about birds, which feed on amphibians (Humbert et al., 2009). According to Humbert et al. (2009), one study reported that over 25% of the amphibian population was injured or killed by a single mowing event using rotary mowers at a height of 7 to 8 cm. The higher cutting height of NWSGs than cool-season forage alternatives is likely beneficial for reptiles and amphibians, especially those of greater body size.

Native warm-season grass establishment, even when limited to crop field buffers, can benefit a number of mammal species by supporting their daily movement across a network of habitat patches (Adams et al., 2013; Ekroos et al., 2016). Habitat quality is enhanced due to the growth habit of bunchgrasses which is upright with gaps of bare ground (Capel, 1991). Bunchgrass growth provides protective overhead cover, allows for native forb and legume establishment in gaps, and facilitates free movement of mammals through gaps of bare ground (Capel, 1991; Miller & Dickerson, 1999). In fact, coverage of forbs in NWSG fields has been observed to be greater than that of cool-season grass fields (Klimstra et al., 2015).

Biomass productivity, habitat, and forage quality of NWSGs and associated forbs can support large herbivores such as *Odocoileus virginianus* (white-tailed deer), *Bison bison* (bison) and small mammals such as *Geomys bursarius* or *Thomomys talpoides* spp. (single pocket gopher) (Moser et al., 2004; Ryan & Marks, 2005). Although published research has not addressed this idea specifically, it is possible that establishment of NWSG stands could help bridge prairie fragments and restore habitat for historical prairie mammal species.

Small mammals are valuable for their role in seed dispersion, and as predators and prey (Klimstra et al., 2015). Producers with interest in game animals should consider ecological benefits of small mammals. Several small mammal species including *Spilogale putorius* (eastern spotted skunk), *Vulpes velox* (swift fox), *Puma concolor* (mountain lion), *Mustela nigripes* (black-footed ferret), *Lepus townsendii* (white-tailed jackrabbit), *Taxidea taxis* (badger), *Cynomys ludovicianus* (black-tailed prairie dog), have been greatly impacted by the loss of NWSG prairies and are now rare or no longer free ranging (Moser et al., 2004). Klimstra et al. (2015) found the abundance of *Sigmodon hispidus* (hispid cotton rats) to be greater in hayed NWSG fields of little bluestem, big bluestem, and indiangrass than hayed non-native cool-season grass fields of tall fescue or orchardgrass. Likewise, other habitat specialists would probably benefit similarly to NWSG habitat when compared to cool-season grasses.

According to Erwin and Stasiak (1979), mammals have varying susceptibility to spring prescribed burns commonly used to manage NWSGs. In a spring burn of big bluestem, little bluestem, indiangrass, and switchgrass, there was no direct mortality of small mammals using underground nests, however, other small mammals were sometimes killed. Prescribed burns are not always feasible for managing NWSG pastures, but where they are employed, leaving 25% of the area unburned may serve as a refuge where wildlife preservation is an objective (Erwin & Stasiak, 1979). Similarly, resting some NWSG fields or parts of fields can provide refuge for small mammals during haying (Klimstra et al., 2015).

Native warm-season grasses can provide valuable wildlife habitat when properly managed. To preserve ground fauna (amphibians, turtles, and small mammals) cutting height should 10 cm or higher according to several sources (Saumure et al., 2007; Humbert et al., 2009). This is much lower than the recommended grass height for many grassland birds. Timing of harvest and frequency of harvest should also be considered. The impact of cutting height and machinery on various wildlife has been addressed, but the impact of post-cutting stages of harvest such as curing, raking, baling, and transport, is largely unknown. Some sources suggest leaving areas of uncut grassland as shelter for wildlife, although this may not be feasible (Gardiner & Hassall, 2009; Moser et al., 2004). Patch-burn grazing (PBG), a management system using rotational burning, seemingly benefits native grassland wildlife while serving as a promising rangeland management tool (Hovick et al., 2014; NcNew et al., 2015). Where burning is not an option, proper grazing management is important to conserve wildlife habitat and avoid damage by overgrazing of NWSG pastures.

Pollinators

The loss of native, wild insect pollinators and resulting economic ramifications are a major concern. Pollination services are highly valuable in agricultural lands. Beneficial arthropods provide an estimated $3.1 billion worth of pollination services each year to crops (Issacs et al., 2009). Another estimate claims that between 1995 and 1998, more than $14 billion in average annual value of fruit, nut, vegetable, and field crops in the United States can be attributed to *Apis mellifera* (honey bees) alone (Lamp et al., 2007). Hines and Hendrix (2005) state that *Bombus spp.* (bumble bees) provide billions of dollars' worth of pollination services to endangered native plant species and various crop species. However, according to Lamp et al. (2007), honey bees account for the majority of insect pollination in United States crop production at around 80%. Most grasses are self-compatible and can be pollinated by wind, however, self-incompatible species require cross pollination, which results from insect pollinators or wind (Lamp et al., 2007). Switchgrass, big bluestem, little bluestem and indiangrass are cross pollinated and produce essentially no seed when self-pollinated (Chen & Boe, 1988; Gustafson et al., 2001; Martínez-Reyna & Vogel, 2002). Many species of insects can pollinate forage plants, but specialist bee species are primarily responsible for cross pollination of natural plant species and crops. Thus, declining bee numbers negatively impacts crop yields and consequentially, profits to farmers (Lamp et al., 2007; Isaacs et al., 2009).

Many bee species such as *Bombus muscorum* (large carder bee) favor open landscapes with the absence of trees, potentially including agricultural lands (Diekötter et al., 2006). Nectar, pollen, or both are required food for survival and reproduction of nearly all beneficial insects (Issacs et al., 2009). Management practices in intensive agricultural systems may limit essential resources for sustaining populations of pollinators. Certain bee species can benefit in the short term from mass-flowering crops, but monocultures only provide floral resources during a limited timeframe, do not support all pollinator species, and do not provide adequate nutritional diversity (Williams et al., 2015). It is doubtful that row crops such as corn and soybeans which do not require insects for pollination provide much value as resources for pollinators. In fact, genetically modified crops, primarily corn and soybeans, with *Bacillus thuringiensis* (Bt) endotoxins for insect resistance has caused some concern about potential impacts on pollinators, specifically butterflies. However, studies have not shown significant adverse effects of Bt crops on nontarget insects (O'Callaghan et al., 2005). As a result, the spread of agricultural land greatly limits nectar and pollen resources as well as nesting and hibernating sites for bees (Diekötter et al., 2006). On the other hand, biodiversity of native perennial flowering plants could benefit pollinators (Issacs et al., 2009). Native warm-season grass dominated prairies often contain abundant and diverse floral resources suitable for many pollinators. Habitat management with a basis on establishing flowering plants provides critical food resources for beneficial insects (Issacs et al., 2009). The incorporation of pollinator habitat and foraging resources in agricultural systems is gaining popularity as a potential solution to the decline of pollinator species due to habitat destruction.

Some studies show that bumble bees have extensive potential foraging distances of up to 6 miles over several days (Walther-Hellwig & Frankl, 2000; Goulson & Stout, 2001). Hines and Hendrix (2005) sought to study resource availability in restored and native prairies and the influence on bumble bee diversity. Floral resources were quantified and compared between native tallgrass prairie remnants and restored prairies surrounded by row crops, pasture, deciduous woodlots, and suburban development. Floral resource availability in grasslands was an important indicator of bumble bee diversity. Bumble bee abundance was predicted more accurately by a model based on the percentage of grassland in the surrounding landscape than a model based on the abundance of plants used by bumble bees at a particular site, illustrating the importance of grassland habitats (Hines & Hendrix, 2005). Additionally, grasslands provide nest sites for queen bumble bees, which prefer withered grass and bunch grasses for nesting places. Almost 90% of the queen bumble bees observed in one study exhibited nest seeking behavior in patches with bunchgrasses as opposed to habitat areas with new grass, annual crops, patches with frequent stones, and patches with moss (Svensson et al., 2000). Mechanical disturbances such as plowing and harvesting disturb bunchgrass nesting habitat. However, incorporation of NWSGs in forage and cropping systems with proper grazing and harvesting management during critical nesting periods could be a successful pollinator conservation strategy.

Hendrix et al. (2010) measured the diversity, richness, and abundance of bee communities in natural small prairies compared to large prairie reserves. Forbs in the prairies were also accounted for in the small prairies in terms of diversity and richness. Bee surveys have shown that numerous bee species are supported by native prairie plant species despite habitat fragmentation. Hendrix et al. (2010) found that site size was unrelated to bee diversity. Forest edges, field boundaries, roadsides, and other marginal grassy areas are suitable and common nesting sites for bumble bees (Svennson et al., 2000). Additionally, plant diversity was positively correlated with bee diversity, suggesting that small habitat fragments with high plant diversity are adequate for supporting bees. In areas dominated by agriculture, small, high quality habitats can be sufficient refuges for bees even when compared with large prairie reserves (Hendrix et al., 2010). Narrow and small grass habitats serve to connect larger resource patches and provide routes for pollinator movement between habitat fragments (Hines & Hendrix, 2005). Native plant species are visited significantly more than introduced species by foraging bumble bees (Hendrix et al., 2010). Plant species which have longer reproductive timespans were visited by the greatest number of bees and provide a consistent season long food base for many bee species. Overall, bee diversity is influenced by a number of factors other than simply physical size of habitat area (Hendrix et al., 2010).

Although bumble bees are more efficient in pollinating crops, butterflies contribute significantly to pollination in seed and fruit production. Butterflies respond quickly to changes in habitat and are good indicators of habitat quality (Stefanescu et al., 2009). The incorporation of legumes, forbs, and sedges with NWSGs may optimize resources for butterflies and other beneficial insects. Some studies have found that species richness of vegetation is positively correlated with insect abundance and species richness (Knops et al., 1999; Haddad et al., 2001). This may be due to increases in floral abundance with increases in species richness. Several studies have found a strong correlation between floral abundance and butterfly abundance, suggesting improved butterfly habitat with incorporation of flowering legumes, forbs, and sedges in NWSG pastures (Reeder et al., 2005; Shepherd & Debinski, 2005; Vogel et al., 2007; Myers et al., 2012). For example, Myers et al. (2012) found that butterfly species richness doubled and butterfly abundance increased six fold in plots with grasses, legumes, forbs, and sedges when compared with mixtures of solely NWSGs or a switchgrass monoculture. Additionally, grassland specialist butterflies require specific plant species to inhabit an area (Stefanescu et al., 2009). The abundance of floral resources is significantly higher with the inclusion of legumes, forbs, and sedges, contributing greatly to increased butterfly species richness and abundance (Myers et al., 2012).

A study by Stefanescu et al. (2009) suggested that species richness of habitat generalist butterflies, and possibly other generalist herbivores, is related to biomass production rather than plant species richness. Native warm-season grasses tend to be taller due to growth habit and management practices, likely enhancing butterfly habitat. Reeder et al. (2005) found a greater abundance of habitat-sensitive butterfly species in vegetation with greater height and vertical density, indicating that grassland butterflies may need habitat structure of tall grasses. Greater butterfly abundance and species richness is probably related to a combination of favorable habitat structure of tall grasses and greater abundance of floral resources, not necessarily species richness alone. In general, cutting reduces abundance and diversity of grassland invertebrates and butterflies are particularly susceptible (Humbert et al., 2009; Dover et al., 2010). Native warm-season grasses are typically cut higher than traditional forage species, which may prevent some butterfly mortality during the harvesting process. If management objectives include maintaining butterfly populations in NWSG forage lands, it would be beneficial to incorporate legumes, forbs, and/or sedges.

Flower-rich native warm-season grasslands can provide habitat for pollinators such as butterflies and bumble bees, which in turn provide pollination services for many cropping systems (Öckinger & Smith, 2007). Grazing intensity is negatively correlated with species richness of bumble bees (Söderström, 2001), so systems which use NWSGs for cattle forage should rotate grazed and harvested fields to allow pollinators to nest and forage in undisturbed fields. Additionally, mowing and other harvesting processes should be carefully managed if pollinator biodiversity is a primary objective. Overall, much potential exists in using NWSGs in forage and cropping systems to promote pollinator diversity.

Soil Erosion Control

The ability of grasses to protect soil and water resources make them fundamental assets in improved environmental protection on agricultural lands (Sprague, 1974; Blanco-Canqui, 2010). Cropland soils are often susceptible to soil loss due to erosion due to lack of ground cover

(Raffaelle et al., 1997). Good cover of grasses and associated litter protects the surface of the soil from raindrop impact, keeping upper channels from being clogged with fine particles, preserving the integrity of open-ended macropores, and improving water infiltration (Sprague, 1974; Blanco-Canqui, 2010). In fact, soil erosion can be nearly eliminated by perennial grasses, which can be planted across entire landscapes or in buffer strips at the edges of cultivated fields (Wedin & Fales, 2009). Native warm-season grasses, in particular, are well-suited for establishment in marginal and erodible soils and this can be beneficial for slope stabilization on susceptible land.

The above ground biomass of NWSGs helps to slow runoff, allowing for greater sediment infiltration in the soil (Sprague, 1974; Rafaelle et al., 1997; Lee et al., 1998). Additionally, NWSGs have extensive root systems (1.5 m to 4.5 m in depth) compared to row crops and cool-season turf grasses, which helps keep soil in place (Moser et al., 2004; BlancoCanqui, 2010). Switchgrass, in particular, is ideal for filtering sediment and reducing runoff due to its strong stalks that remain stay upright under water flow and deep root system which stabilizes soil (Mersie et al., 1999). Lee et al. (1998) observed that switchgrass was more effective at sediment removal from surface runoff in the long term than cool-season grasses including smooth brome, *Phleum pretense* (timothy) and tall fescue. Native warm-season grasses have stronger stems and roots, taller growth, and usually produce more litter than cool-season grasses, improving their ability to trap runoff sediment and nutrients (Blanco-Canqui, 2010). For example, filter strips of switchgrass trapped 16% more sediment than equal width strips of fescue, and it took 4 m of fescue to reduce the same sediment equivalent of 0.7 m of switchgrass (Blanco-Canqui et al., 2004).

Belowground characteristics of NWSGs may help improve soil structural properties and thus provide greater opportunity for water quality improvement (Blanco-Canqui, 2010). When compared to row crops, NWSGs have been shown to increase soil macroporosity and reduce bulk density (Bharati et al. 2002; Murphy et al. 2004; Rachman et al. 2004; Blanco-Canqui, 2010). After 10 years of grass establishment, macroporosity of soil under switchgrass hedges was found to be more than two times greater than soil under row crop management (Rachman et al., 2004). Another study reported 17% lower bulk density in soil under switchgrass than that of corn (Bharati et al., 2004). Native warm-season grasses also may reduce bulk density when compared to cool-season grasses. Murphy et al. (2004) found that soils under NWSG fields dominated by big bluestem and little bluestem had an average bulk density that was 10% lower than under smooth brome. This may be a function of differing management and increased traffic on the cool-season grass fields. It should be noted that measurable changes in soil properties due to NWSG establishment may not be observed for many years (Blanco-Canqui, 2010).

Soil hydraulic properties such as water infiltration, hydraulic conductivity, and water storage are positively correlated with improvements in soil structural properties due to NWSG establishment. For example, water infiltration over a 60-minute interval was five times greater under switchgrass compared with row crops (Bhatari et al. 2002). Studies have also shown that soil moisture content under switchgrass is greater than under crop fields (Bhatari et al., 2002; Rachman et al. 2004). One study showed that switchgrass reduced surface runoff by 11% when compared to bare soil (Mersie et al. 1999). Increases in macroporosity and decreases in bulk density associated with establishment of NWSGs are important factors in improvement of hydraulic conductivity. Rachman et al. (2004) observed hydraulic conductivity within switchgrass hedges 18 times greater than a row crop system. Nevertheless, it may take 15 years or more to observe increases in hydraulic properties associated with NWSG establishment (Corre et al., 1999; Blanco-Canqui, 2010). This may explain why Bhatari et al. (2002) found greater infiltration rates under cool-season grass sites dominated by smooth brome, timothy, and *Poa pratensis* L. (Kentucky bluegrass) than under switchgrass, which had only been established for six years.

As a result of improved soil hydraulic properties and greater infiltration rates in NWSG soils, pesticide runoff can be reduced. Infiltration rate is critical in the removal of pesticides from surface runoff and increases greatly with the presence of grasses compared with unvegetated soils (Mersie et al., 1999; Belden & Coates, 2004). Rankins et al. (2001) showed that initial runoff losses of fluometuron and norflurazon herbicides used in cotton production were reduced by 53% and 46% respectively by 3 m x 4 m filter strips of big bluestem, eastern gamagrass, and switchgrass. Losses of atrazine and metolachlor in another experiment were reduced by 11% and 15% respectively in 0.9 m x 2 m tilted beds planted with switchgrass when compared to those with bare soil (Mersie et al., 1999). Similarly, Belden and Coates (2004) found that mixed prairie grasses, including big bluestem, switchgrass, and indiangrass, were more effective than smooth brome, tall fescue, or individual NWSGs at degrading atrazine and metolachlor. Leached atrazine and metolachlor were 30% and 11% lower respectively, in mixed NWSGs compared to fescue. Additionally, the mixed NWSGs increased atrazine mineralization by 260% and formation of metolachlor-bound residue by 760% when compared to unvegetated soil columns (Belden & Coates, 2004).

Native warm-season grasses can serve as windbreaks, reducing wind erosion in susceptible areas (Moser et al. 2004). Native warm-season grasses leave residues on the soil surface which inhibit erosion of the soil due to wind (Blanco-Canqui 2010). It has been observed that when compared to tillage, no-till management has little influence on dry aggregate stability of soil, which is a significant indicator of wind erodibility of soil (Blanco-Canqui & Lal, 2009).

Unlike trees which buffer wind at great heights, grasses control wind velocity near the soil surface, effectively reducing erosion (Blanco-Canqui, 2010). This benefit is particularly substantial in northern climates where snowfall is common and the stubble associated with NWSGs traps snow, protecting the soil from wind erosion and increasing infiltration (Fargione et al. 2009). Bilbro and Fryrear (1997) found switchgrass to be a more effective wind barrier than *Habiscus cannabinus* (kenaf), *Sorghum bicolor* (forage sorghum), and slat-fencing throughout the winter. These protective effects were due to the longevity of stem biomass, minimal leaf drop, and high resistance to lodging.

Carbon Sequestration

Carbon sequestration is an important ecosystem service by which plants, including NWSGs, store carbon in their biomass and soils. Unlike forests, grasslands primarily store carbon in the soil rather than in the vegetation (Boller et al., 2010). Some photosynthate travels through plant roots and fallen litter into the soil, where it is decomposed and either returned to the atmosphere through respiration and leaching or stabilized as a component of soil organic matter (SOM). The carbon in the SOM that is stabilized has a half-life of decades to centuries in the soil. The provision of carbon sequestration in the soil can mitigate climate change through the transfer of carbon from the atmosphere to stable forms in soil (Powlson et al., 2011). However, land use changes have hindered the carbon sequestration and storage capacity of ecosystems (White et al., 2000).

Carbon sequestration is associated with increased soil organic carbon (SOC) stocks, which provides more fertile soils with improved properties such as reduced bulk density, increased water holding capacity, improved soil structure and increased microbial activity. Grasslands account for an estimated 34% of global carbon stocks on land (Boller et al., 2010).

Soil organic carbon stocks are depleted by intensive agriculture and land use change from grassland or forest cover to cultivation. A compilation of data shows that land use change from pasture to cropland results in a 59% decrease in SOC stocks on average (Söderström et al., 2014). Oxidation, mineralization, leaching, erosion, and minimal SOM return further complicate the problem in cultivated land. Conversely, a change in land use from cultivation to forest or grassland will essentially always result in an increase in SOC because cultivated soils generally have a much lower SOC content (Powlson et al., 2011). After establishment of grass or trees, the rate of SOC increase will plateau at a new SOC equilibrium (Powlson et al., 2011). The incorporation of NWSGs as a summer forage resource to increase forage production also may increase SOM and initiate carbon sequestration (Conant et al., 2001). The largest terrestrial global organic carbon stock is in the soil, consisting of approximately twice the atmospheric carbon levels (Jobbagy & Jackson, 2000; Purakayastha et al., 2008; Powlson et al., 2011). Cultivated soils account for 12% of the SOC stock and over 33% of the global land surface is represented by agricultural soils (Söderström et al., 2014). This presents a substantial opportunity to influence atmospheric carbon concentration with agricultural management practices (Powlson et al., 2011; Söderström et al., 2014).

Conant et al. (2001) states that conversion of land from cultivation to grassland is among the most significant management practices to increase the rate of carbon sequestration compared to fertilization, improved grazing management, sowing of legumes, earthworm introduction, and irrigation management improvements. Soil organic carbon distribution through the soil profile is heavily influenced by vertical root distributions and allocation of roots and shoots (Jobbagy & Jackson, 2000). Below ground production associated with sowing perennial NWSGs increases below ground carbon inputs, potentially resulting in increased SOC (Conant et al., 2001;

Rosenzweig et al., 2016). Tillage usage in cropland reduces SOC and increases soil erosion (Liebig et al., 2005). Data shows that soil carbon stocks can increase 19% after a land use change from cropland to pasture (Söderström et al., 2014) or over 3% annually (Conant et al., 2001). The use of NWSGs is feasible as an inexpensive and efficient method of improving carbon sequestration to mitigate atmospheric CO_2 accumulation, decrease soil erosion, and improve nutrient and water retention of the soil and overall soil quality.

The rate of carbon sequestration by NWSGs has proven to be highly variable due to climatic variables, native vegetation, grass species, fertilization, soil type, nutrient status, original soil carbon and establishment status of the grasses (Conant et al., 2001, Omonode & Vyn, 2006). Liebig et al. (2005) found greater SOC at depths of 30-90 cm within switchgrass stands when compared to cultivated cropland. Similarly, Omonode and Vyn (2006) found that switchgrass stands generally have higher SOC than mixed grass stands of big bluestem, indiangrass, and little bluestem. Native warm-season grasses stored 9% more SOC than croplands while switchgrass alone stored 8% more SOC than mixed NWSG stands (Omonode & Vyn, 2006). However, Bonin et al. (2014) found that carbon inputs were higher with diverse native grass mixtures than with switchgrass monocultures. The most diverse mixture in this study included several forbs, legumes, and a C_3 grass rather than exclusively NWSGs which may explain some differences in conclusions (Bonin et al., 2014). Switchgrass is estimated to produce more root biomass annually at greater depths (30 cm or deeper) than wheat and corn crops (Gregory et al., 1978; Zan et al., 2001; Frank et al., 2004). Greater rooting depth and biomass may increase SOC storage at higher depths in perennial grassland soils compared to annual row crops (Liebig et al., 2005; Omonode & Vyn, 2006). Greater root biomass of NWSGs and rhizodeposition of photosynthetically fixed carbon may be a key factor in the accumulation of more SOC below NWSGs than croplands (Liebig et al., 2005; Omonode & Vyn, 2006).

Carbon sequestration may be greater when NWSGs are managed for biomass production compared to grazing (Bonin et al., 2014). Grazing may reduce competitiveness of native grasses and has been shown to allow increased establishment of cool-season grasses and annuals in NWSG pastures (Bonin et al., 2013). Additionally, Bonin et al. (2014) observed a generally higher proportion of carbon from C_4 plants at soil depths below 15 cm in ungrazed NWSG pastures than that of grazed NWSG pastures. Total root length was not significantly different between grazed and biomass production plots, however, the increased carbon storage in deeper soils could be explained by the higher root volumes found at such depths under NWSGs managed for biomass production (Bonin et al., 2014). The total pool of carbon was not affected by management for grazing or biomass production or by species composition during this experiment, however, the grasslands had only been established for 4 years (Bonin et al., 2014). Species that commonly invade NWSG pastures root almost exclusively in the upper 20 cm of the soil, while substantial portions of switchgrass and big bluestem roots can be present below 30 cm depth when left ungrazed (Høgh-Jensen & Schjoerring, 2001). Grazing of over 20% of the above ground foliage of perennial grasses may result in a suppression of the relative growth rate of their roots and may increase competition for nutrients with shallower rooted species (Oesterheld, 1992). After 42 days without grazing, root to shoot ratios recover despite grazing intensity (Oesterheld, 1992).

Changes in soil carbon stocks may occur over long periods of time as demonstrated by Ma et al. (2000) who observed that after switchgrass establishment, SOC changed more slowly over time than other carbon related measurements such as carbon mineralization, microbial biomass carbon, and carbon turnover. These findings are consistent with Medina-Roldán et al. (2012) who observed slower carbon and nitrogen cycling in ungrazed pastures, reduced microbial activity, reduced net NH_4^+ mineralization, and increased ratio of dissolved organic nitrogen to dissolved inorganic nitrogen, but no notable change in total carbon and nitrogen stocks in the soil. When compared to cool-season grasses, Bonin et al. (2014) found that NWSG pastures were not significantly different in terms of soil carbon storage. However, this could be attributed to a loss of SOC during establishment of the NWSG pastures which were fallow for a year during conversion as opposed to the cool-season grass pastures which were undisturbed for that period (Bonin et al., 2014).

While land use change from cultivation to grassland has the potential to significantly improve carbon sequestration, it may take centuries to restore the total carbon stock of the restored grassland to that of a native prairie. In fact, in one study total carbon stocks of cultivated soils were only 46% of that of an undisturbed native prairie but reached 69% within 35 years after restoration to grassland (Rosenzweig et al., 2016). A model developed from the same study estimates that it would take 333 years for a restored grassland to reach the total carbon stock of an undisturbed native prairie (Rozenzweig et al., 2016).

Native warm-season grass fields are more valuable from a carbon sequestration standpoint than conventionally cultivated agricultural crop systems. Conceivably, with good agricultural management, prior SOM losses can be reversed, resulting in sequestration of atmospheric carbon. Conversion of land from cultivation to well-managed grassland could add up to a potentially significant carbon sink. Particularly, SOC stored deeper in the soils as a result of increased rooting depth of perennial NWSGs is more stable and less prone to mineralization than SOC stored shallower in the soil (Liebig et al., 2005). Incorporation of NWSGs as a summer forage for cattle or in lands set aside for conservation can collectively make an impact on total carbon sequestration.

Aesthetics and Cultural Ecosystem Services

The use of NWSGs in pastures can contribute to human well-being and cultural advancement in areas such as aesthetics, recreation, management practices, and cultural ties to land. Gibson (2009) stated in his *Grasses and Grassland Ecology*:

> Grasslands evoke emotion, they are the largest biome on Earth, they represent a tremendous source of biodiversity, they provide important goods and services, and they are the place where as a species, we first stood up and walked.

Grasslands across the nation and globally have been lost and fragmented by agriculture, development, and other human activity. Development and land use conversion from native conditions results in habitat fragmentation, decreases in species diversity, and disruption of hydrological and nutrient cycles. However, it is now becoming apparent that productivity and environmental services can coexist in agricultural landscapes (Mander et al., 2007). Further, the loss of native landscapes due to human activity has given rise to a cultural desire to restore what has been lost (McMahan, 2006).

Native grasslands have multifunctional properties (Mander et al., 2007), exhibiting capability to provide aesthetic appeal and recreational activities such as sightseeing and photography of natural scenery, flora and fauna while controlling various ecosystem processes (Cordell, 2008). Incorporation or preservation of certain features on agricultural land can be an important technique to benefit agricultural productivity, the ecosystem, and the public.

Specifically, NWSGs can conserve and restore important environmental services while enhancing aesthetic and cultural aspects (Mielke, 1993).

The growth form of NWSG stands and management practices applied to NWSG pastures create a unique and unconventional agricultural landscape that people may not be accustomed to. However, studies conducted to determine aesthetic quality and perceived beauty of more unorthodox, ecological landscapes have shown that such natural landscapes can align with cultural concepts of aesthetic beauty (Fuller et al., 2007; Lindemann-Matthies & Bosse, 2007; Lindemann-Matthies & Marty, 2013). Landscapes with infrequent mowing and weeding and minimal pesticide and fertilizer usage, such as NWSG pastures, can create the perception of naturalness through a diversity of plant species and structure (Lindemann-Matthies & Marty, 2013). Human aesthetic preferences are stronger for more species rich landscapes and much weaker for intensive monoculture (Lindemann-Matthies & Marty, 2013; Gao et al., 2014). Native warm-season grass pastures often incorporate a number of different species, including a variety of NWSG species, cool-season grasses, and forbs, creating an enticing visual display. Further, the gently rolling topography of native grasslands is a beautiful asset of rural America (Sprague, 1974).

Native plants and, more specifically, native grasses have gained popularity at a variety of use levels in the 21st century due to benefits such as their natural appearance and low maintenance (McMahan, 2006; Meyer, 2011). A variety of NWSG species are well suited for horticultural and restorative efforts, in addition to their provision of environmental services. Big bluestem, switchgrass, indiangrass, little bluestem, and eastern gamagrass are all also common ornamental grasses in the United States. Several cultivars of switchgrass have been developed for a variety of characteristics. ‘Shenandoah,’ ‘RR1,’ and ‘Prairie Fire’ flaunt red-purple foliage, which can very appealing. ‘Heiliger Hain’ is an awarded ornamental switchgrass cultivar. The foliage of little bluestem generally changes from blue to purple, red, and orange in the fall. Indiangrass is tall and upright, with blue foliage in cultivars such as ‘Sioux Blue’ and ‘Steel Blue’ (Meyer, 2011). While ornamental cultivars would not necessarily be useful as forage resources, the development of ornamental cultivars shows an interest and appreciation for their natural appearance and a desire to exaggerate their desirable visual traits. Furthermore, NWSGs are diverse and variable between regions in the United States which can contribute a sense of place to the landscapes in which they are used (Meyer, 2011).

Seasonal fluctuations and biodiversity in NWSG systems generate aesthetic appeal through variance in color, form, texture, and lines. Flowers of native forbs often incorporated with NWSGs offer brilliant color during bloom, despite having small individual flowers (Mielke, 1993). The vivid blooms of many native flowering species have adapted to attract insects for pollination. Additionally, bloom periods of native flowering plant species vary greatly and season long bloom can be easily achieved using native plants. Plants including NWSG have coevolved with their native region to differ in form from plants from other regions for advantages in resource acquisition such as light, moisture, and soil nutrients. The natural form and character of native plants negates the need for excessive maintenance and such practices actually compromise their beauty (Mielke, 1993). Invasive species have aggressive spreading growth habit, creating monotony in the landscape which is visually unappealing, among many other problems with invasive species. While exotic species are not always invasive, existing native and exotic species can be outcompeted by invasive species and lost from the landscape.

The incorporation of NWSGs also provides a valuable opportunity for agritourism. An increasing number of outdoor recreationists are drawn to native grasslands due to species diversity of flora and fauna, scenic topography, and the presence of domestic animals (Sprague, 1974). According to Boller et al. (2010), grazing animals are valued due to association with animal welfare. Thus, the possibility of secondary uses of pasture and rangeland for recreation is present. Already, guest ranches are popular and provide advantageous supplemental income to owners of rangelands (Sprague, 1974). However, as the environment and sustainability movement is rapidly gaining popularity, recreationists may have higher interest in forage enterprises which implement management practices to promote multiple ecosystem services. As previously stated, NWSG pastures can increase biodiversity, which is crucial environmentally and to human economy and survival (Buckley, 2010). Biodiversity is threatened by a number of human activities such as agriculture and urban development. Buckley (2010) found that conservation tourism efforts globally have aimed to convert land use from agriculture to conservation, reintroducing native wildlife to improve tourism potential. Native warm-season grass pastures can serve as multiple-use lands by producing critical agricultural resources while promoting conservation and increasing native wildlife abundance. The use of NWSGs in forage systems can partially convert land use to conservation, without hindering production. The provision of wildlife habitat via NWSG pasture and rangeland provides high quality hunting opportunities, which may be of interest to landowners because many sportsmen pay premium prices to experience such opportunities (Sprague, 1974). Sportsmen, in turn, contribute greatly to environmental conservation programs through taxes on the purchase of equipment and hunting licenses. Gao et al. (2014) found that agritourism farm visitors prefer to observe natural features such as wildlife, water, and native flora on agricultural land. This is consistent with observations by Cordell (2008) that viewing, photographing, identifying, visiting and observing nature including scenery, wildlife, and plants are among the fastest growing nature-based recreational activities in terms of total participants and total days of participation per year between 2000 and

2007. Structural diversity and species richness common in native grasslands provide resources for wildlife and pollinators, offering opportunity for wildlife viewing, photography, and educational experiences (Fuller et al., 2007). Additionally, NWSGs themselves and other associated native pasture plants may be of interest to native plant enthusiasts. This research suggests that Americans' have a strong and increasing interest in nature, specifically plants, which may generate support for conservation and restoration of native grass species such as NWSGs in agricultural settings. Moreover, empirical evidence suggests that plant species richness and bird species richness in landscapes are positively associated with human well-being measures such as reflection and distinct identity (Fuller et al., 2007).

LIMITATIONS OF NATIVE WARM-SEASON GRASSES

Crop and Livestock Production Limitations

The use of NWSGs in forage and livestock systems has several limitations. One key benefit of NWSGs is the provision of forage during the summer months when cool-season grasses are less productive. However, establishment may be a challenge when integrating NWSGs (Ball et al., 2007; Keyser et al., 2011). Native perennial seeds are small and slow to germinate. Seedlings generally have low vigor and competition control is crucial for their success (Keyser, 2016). The non-invasive, perennial growth habit causes plants to be slower to develop substantial above ground vegetative structure. Native warm-season grasses tend to primarily establish root biomass in the first two years as opposed to above ground growth (Capel, 1991; Keyser et al., 2011). A well-prepared seedbed, shallow seeding, and a robust long-term weed management program are critical. Warm season grasses evolved under intermittent grazing and as a result are less tolerant of frequent and heavy grazing than many species of cool-season forage grasses (Capel, 1991; Anderson, 2000). Once established, management for hay harvest must keep grasses from getting too tall and coarse, while not allowing overgrazing or repeated close haying (Keyser et al., 2011). This also makes integrating NWSGs within a cool-season grass pasture extremely difficult, thus, NWSGs should be established in separate areas. It is well-known that NWSGs are less digestible and lower in CP than cool-season alternatives (Tracy et al., 2010). Native warm-season grasses tend to be early maturing, meaning there is a shorter window of maximum nutritional value because as the grasses mature, CP and LSR ratio decrease (Temu et al., 2014). The incorporation of herbaceous forbs and legumes in a pasture has been suggested to improve nutritive quality of NWSGs. However, cattle have a tendency to consume mostly grasses, while other livestock such as sheep and goats may graze herbaceous forbs, legumes, and even weeds in a pasture (Abaye et al., 2009). The inclusion of native forbs and legumes to enhance forage nutritive value is only effective if they are palatable to the livestock grazing them.

Native warm-season grasses respond differently to management practices than cool-season grasses. According to current grazing research, NWSGs do not tolerate continuous and heavy stocking and rotational stocking with adequate rest is necessary. Lengthy rest periods of greater than 40 days are required for tall and medium height NWSGs when grazed to lower than 20 cm. Grazing periods may be extended if stubble height can be maintained between 25 and 40 cm (Capel, 1991; Anderson, 2000). Intensive stem management is also necessary for high quality NWSG forage. If shoot apices are removed by grazing during jointing and stem elongation, leaf growth may be stimulated and mature stem development reduced, improving digestibility. In mixed stands of NWSGs, management becomes complicated as maturity time periods vary. Cattle will selectively graze less mature, leafier grasses resulting in overgrazing of those and underuse of the more mature grass species (Anderson, 2000). During the winter, NWSGs are unproductive. Therefore, the forage system must include additional species to produce forage during NWSG dormancy. As a result, NWSGs are more beneficial in combination with cool-season grasses rather than as an alternative.

Wildlife and Pollinator Habitat Limitations

When incorporating NWSGs for pollinator and wildlife benefits, it is important to consider all taxa which will be impacted by management and conservation actions. For example, optimal timing and frequency of cutting varies greatly between species; a summer cut is optimal to avoid grassland bird nesting season, however, for spiders and some insects, summer cuts are more detrimental than those in spring or fall (Humbert et al., 2009). Also, due to complexity in habitat needs for different species of grassland birds, it would be impossible to manage habitat that is optimal for all species. Davis et al. (2008) found that bee and butterfly species in prairie fragments have diverse habitat requirements, and management for their conservation is complex. When promoting species abundance and richness of butterflies, it is important to note that caterpillars, the larval stages of butterflies and moths, are considered a major agricultural pest of many crops.

Grazing of NWSGs in forage systems may conflict with NWSG benefits to pollinators and wildlife (Söderström, 2001). Many species of pollinators and wildlife depend on certain height and structural features of NWSGs which are diminished under intensive grazing, haying, or other management practices. Grazing and harvesting impacts pollinators by removing critical food resources and potentially resulting in mortality or injury from cutting equipment. Cutting is part of silage and hay production to provide winter feed for cattle, or sometimes to maintain conservation habitats and prevent grassland succession (Humbert et al., 2009). Wildlife and pollinators can be greatly impacted by harvesting processes, and timing may be an important factor in predicting damage (Giuliano & Daves, 2002; Humbert et al., 2009; Isaacs et al., 2009). Direct and indirect effects of mowing can account for greater than 50% mortality of invertebrates (Humbert et al., 2009). Theoretically, adult butterflies are less susceptible to injury or mortality in late fall harvests when they are highly mobile than earlier in the fall when they are immature and immobile. However, Dover et al. (2010) found no evidence that butterfly declines are due to relocation from cut meadows. Humbert et al. (2009) found that invertebrates occurring higher in the vegetation, including many pollinators such as bees and butterflies, are more vulnerable to injury or mortality by mowing practices than species inhabiting closer to the ground. This would indicate that butterflies are actually less susceptible to cutting in their immobile, immature stage. It is possible to limit the impact of mowing on wildlife by using cutter bar mowers, which are less damaging than rotary mowers or flail mowers, cutting at 10 cm or higher to preserve ground fauna, and timing cuttings around critical periods for target conservation species (Saumure et al., 2007; Humbert et al., 2009; Isaacs et al., 2009; Erb & Jones, 2011). Additionally, it is possible that leaving more time between cutting, windrowing and baling would allow surviving organisms to relocate out of windrows and not be removed during baling (Humbert et al., 2009).

Studies have evaluated grassland bird response to NWSG restoration. However, several studies have found that when compared to cool-season grasslands, native warm-season grasslands have no greater abundance or nesting success of several bird species (Klett et al., 1984; King & Savidge, 1995; Delisle & Savidge, 1997; Norment et al., 1999; McCoy et al., 2001b; Moser et al., 2004). Fletcher and Koford (2002) did not separate data taken from predominately cool-season grass fields from that of NWSG fields, so could not state that grassland bird habitat was diminished in cool-season grass fields. The grasslands observed in many of these studies were rarely disturbed and results may have been different if the grasslands were managed by prescribed fire, mowing, or grazing (Delisle & Savidge, 1997; Norment et al., 1999; McCoy et al., 2001b). Recommendations based on production avoid late season harvesting or grazing of NWSGs, however wildlife biologists are interested in preserving grassland height for wildlife cover until mid-summer. While NWSG pastures managed to protect wildlife habitat increase forage yield, nutritional value of NWSGs is compromised (Chamberlain et al., 2012). Prescribed fire is recommended for maintaining NWSG stands in early succession, however, current-year burn patches are lower in nest density and success of some grassland birds due to higher predation and less cover (Churchwell et al., 2008). Furthermore, time and equipment required to create and maintain fire breaks may be a limiting factor (McNew et al., 2015). Incorporation of native forbs in NWSG pastures can be beneficial in several aspects, particularly to pollinators. However, this results in increased difficulty when controlling weeds because broad-leaf herbicides will kill intentionally planted native forbs (Reeder et al., 2005).

According to Kaufman and Kaufman (2008), haying of NWSGs (big bluestem, indiangrass, and little bluestem) in late fall results in lower abundance and species diversity of small mammals, when compared to NWSGs which were not hayed. However, the hayed sites in this study were cut to only 5-10 cm tall while control sites were over 100 cm in height. Height recommendations for grazing and haying of NWSGs for wildlife benefits vary between 10 and 40 cm (Saumure et al., 2007; Humbert et al., 2009; Erb & Jones, 2011; Harper et al., 2015), which may have been sufficient for the small mammals observed by Kaufman and Kaufman (2008). Establishment of NWSGs likely benefits grassland specialist species in particular. Habitat generalists, such as *Mus musculus* (house mice) and *Peromyscus leucopus* (white-footed mice), do not heavily depend on plant community composition and therefore are equally as abundant in cool-season grass fields (Klimstra et al., 2015). Furthermore, highly mobile species may not greatly benefit from NWSG establishment on a single forage and cropping operation. In such cases, conservation management must occur on a much larger scale to significantly benefit wide ranging species (Söderström, 2001). On the other hand, species with a smaller range may rely on field crops rather than conservation areas if conservation areas are not within their range (Walther-Hellwig & Frankl, 2000).

Carbon Sequestration Limitations

Several factors should be considered when estimating overall carbon sequestration benefit potential of NWSG establishment. A management practice generates ecosystem services if there is a net transfer of carbon from the atmosphere to the soil or vegetation. It is important to consider that not all management practices that result in an increase in SOC are due to a transfer in atmospheric carbon to the soil. Limitations exist when planting native grasses for the acquisition of carbon sequestration benefits. For example, there is a limited quantity of carbon which can be stored in soils. Additionally, carbon sequestration is not permanent and can be reversed. For example, the establishment of NWSG must be maintained indefinitely for the ecosystem service to continue. If the grassland is converted back to row crops or developed, the increased SOC stock will be lost to the atmosphere. Additionally, overgrazing of grasslands can result in decreases in SOC (Conant et al., 2001). Due to these limitations, the environmental benefits of soil carbon sequestration should be carefully evaluated and not overemphasized.

Aesthetic and Cultural Limitations

Aesthetically, native plants and more specifically native grasses are not desirable for all people. Society has shaped the expectation for well-maintained and neat landscapes, within which NWSGs may look unkempt and scrubby. Another study evaluated the perceived naturalness of a landscape and found that tall dense vegetation such as forested land is perceived to be more natural than lower more open landscapes such as grasslands. Lower aesthetic appeal may be associated with the perceived less natural appearance of grasslands (Cary & Williams, 2001). Also, establishment of NWSGs is much more demanding than cool-season grasses, causing some reluctance to use them for slope stabilization. Cool-season grasses such as perennial ryegrass, Kentucky bluegrass, tall fescue, and orchardgrass are frequently prescribed as a component of slope stabilization due to their availability, affordability, and ability to establish during any season other than the middle of summer (Miller & Dickerson, 1999). Weed competition must be intensively managed during NWSG seedling establishment due to their initial period of root development rather than above ground vigor. Additionally, specialized seed drills are necessary to seed some NWSGs such as big bluestem and indiangrass because conventional grass seeders do not work well with their seeds which are chaffy with long awns (Capel, 1991; Miller & Dickerson, 1999).

CONCLUSIONS

Based on this review of available research, the integration of NWSGs into conventional forage-livestock systems should increase the output of ecosystem services compared to foragelivestock systems without NWSGs. The greatest appeal of using NWSGs in forage systems is their capability of filling the summer forage slump of cool-season grasses. Forage-livestock producers may also be inclined to adopt NWSGs in pasture and hay land because of their practical benefits such as lower input requirements during a time of increasing costs of fertilizer and restrictions on their usage. Management of NWSGs is different than that of cool-season forage grasses and good management is critical to provide sustainable provisioning of ecosystem services. Pollinator and wildlife habitat, root growth and potential carbon sequestration, runoff and erosion mitigation, and overall plant health could be sacrificed if NWSGs are mismanaged by overgrazing or aggressive hay harvesting. The potential for NWSGs to improve overall productivity and environmental sustainability and become an integral part of future forage-livestock agroecosystems is evident. Forage-livestock producers, however, need more financial incentive to help them adopt NWSGs in their systems. Future work that focuses on quantifying the economic value of ecosystem services in grassland agriculture would be a useful first step as this could help guide policy to establish subsidies for producers who integrate NWSGs into their forage systems.

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