Native Warm-Season Grass Roles in Soil and Water Conservation: A Literature Synthesis

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I. BACKGROUND

A) GRASSLAND VEGETATION PREFACE

Native grasses discussed throughout this paper are adapted to the soils and climates of the United States (Appendix 1) and their range may include portions of Canada and Central America (Parrish and Fike, 2005). These native bunchgrasses (i.e., grass species that grow in discrete clumps rather than in sod-like carpets) sequester carbon, reduce soil erosion, filter nutrients and sediment, and provide habitat for wildlife and pollinators. Several studies have investigated the benefits of native warm-season grasses on biodiversity (Burger, 2005), soil conservation (Shifflet and Darby, 1985), water quality enhancement (Dillaha et al., 1989), stream bank protection (Gamble and Rhoades, 1964), and have determined there are substantial benefits to growing native species for conservation. However, a number of non-native grass species – both bunchgrasses and sod-forming – have been cultivated and widely adopted for soil and water conservation uses (Rankins and Shaw, 2001). Therefore, the aim of this paper is to compile studies and evaluate the relative benefits of native and introduced grasses for conservation purposes; specifically, wildlife habitat, and soil and water quality enhancement.

For the purposes of this paper, we will refer to native warm-season perennial bunchgrasses as native grasses (e.g. Appendix 2), which are characterized by their erect growth habit and range of dispersal as they are generally polymorphic, which translates into greater adaptability and resistance to periods of biotic and abiotic stress. Although there are cool season bunch grasses and sod-forming grass species native to the United States, this paper focuses on the warm-season bunchgrass species most commonly used in the eastern United States for conservation purposes. In efforts for simplification, introduced forage grasses e.g., bermuda (*Cynodon dactylon*), tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh.]), and brome species (*Bromus*) will be generalized as sod-forming grasses, even though, their growth habit, photosynthetic pathways, input, and edaphic requirements greatly differ; however, their aggressive colonization pattern is similar, and therefore, they are widely used as perennial forage species and will be collectively classified as such.

Compared to non-natives, mixtures of natives support a species-rich insect and pollinator community and wider associated biodiversity. Native grasslands are arguably the most threatened ecosystem in the U.S. (Samson and Knopf, 1994), which has resulted in the decline of many species, including grassland bird populations. These losses are mainly attributed to grassland conversion to agriculture, including intensive rowcrop production and conversion to introduced sod-forming forage.

Concerns about climate change and energy security have stimulated land use change, including increases in the acreage of cultivated farmland, thereby further increasing the fragmentation of grassland vegetation. In the U.S., it is predicted that within 20 years, dual-purpose, native warm-season crops [e.g., Switchgrass (*Panicum virgatum* L.)] could account for significant areas of rural land, (McLaughlin and Walsh, 1998). Perennial native biomass and forage crops have several advantages: they are not food crops; there is no annual cultivation cycle; they achieve rapid growth with low inputs (fertilizer and herbicide), and their growth habit can result in substantial greenhouse gas reduction. Native prairie bunchgrasses are becoming increasingly important as forage grasses in the humid east, because of their capacity to grow during hot summer months when water availability limits the growth of most other species (Moser and Vogel, 1995).

Native grasses have always been a part of North American prairie communities and thus served as forage for native wildlife, and subsequently for cattle grazing on rangeland (Wolf and Fiske, 1995). That is however, until the late 1940's, when the USDA began promoting exotic sod-forming forage grasses [(e.g., tall fescue, bermuda, bahia, etc., as some 'set-aside' programs allow for their enrollment (4% tall fescue currently in CP1; Burger, 2005)]. Such sod-forming species are now widely used in forage systems throughout the humid east; thereby, greatly reducing the amount of native forage grasses and their associated species. However, in the last 50 years, various producers have adopted native grasses as cultivated forage crops to fill in summer production gaps left by cool-season forages (Parrish and Fike, 2005), particularly eastern gamagrass, big bluestem, and switchgrass. However, to date, forages in the U.S. are overwhelmingly composed of cool-season grasses that produce little warm-season forage and as such, may limit profitability of both stockering and cow-calf operations. Use of warm-season bunchgrasses established for biofuels feedstock as a component of integrated forage systems could increase total biomass production and provide a substantial economic benefit through increased stocking rates and weight gains of grazing cattle, all while providing habitat for wildlife.

Native grasses grown for forage, soil conservation, water conservation (e.g., filter strip), wildlife habitat, or as a biofuel feedstock, all provide similar ecosystem functions. These functions are discussed and compared to sod-forming grasses throughout this paper. In the succeeding section we will briefly describe grassland distribution and adaptation, agronomic characteristics of native perennial bunchgrasses, then their role in facilitating habitat for various species; thereafter, we will compare the current literature on soil conservation and water quality benefits. The specific goal of this paper is to assemble literature on the impacts of growing native perennial bunchgrasses and their subsequent effects on i) soil conservation (i.e., soil stabilization, soil organic carbon formation, etc.), and; ii) water quality, (i.e., sediment control and infiltration enhancement) compared to introduced sod-forming species. For a general list of native grass species that are described in the coming text, refer to Appendix 2. Lastly, the region under investigation in this paper is the eastern, humid zone characterized by extensive use of temperate perennial grasses prominent between 33º and 40º N latitude and east of 96º W longitude.

B) Trends in Grassland Distribution

In North America, the largest vegetative province is the native prairie, and grasses that make up this ecosystem are an integral component of this ecosystem, considering at one time, grassland vegetation on the continent was more extensive than any comparable group of plants, covering about one-third of earth's terrestrial surface (Samson and

Knopf, 1994). Historically, grasslands have made up of ca. one billion acres in the U.S., or approximately one half the landmass of the 48 contiguous states (Appendix 1). However since early European settlers arrived to the U.S., particularly since the advent of mechanized agriculture (Appendix 3), and the introduction by the U.S. government of myriad exotic species from all over the world, native grassland prairies have declined significantly. Other grassland ecosystem losses have been due to human development (particularly the intensification of agriculture) and suppression of natural disturbance regimes (Sampson and Knopf 1994). Such early-successional habitat and biodiversity losses of in North America (Harper 2007) have mirrored effects of natural habitat loss and increased agricultural intensification that occurred in Europe (Robinson and Sutherland 2002). This is evidenced by a 260 million acre decline in grassland distribution west of the Mississippi River in the 100 years from1850 to 1950, with the majority converted to cultivated cropland. In the 40 years from 1950 to 1990, another 27.2 million acres of grassland was lost (Ramankutty and Foley, 1999). Privately owned land comprises the largest proportion of grassland habitat east of the 100th meridian, however, acreage in this region has sharply declined in the past 40 years due to grassland conversion to pasture and hay fields (Herkert et al., 1996).

Extinction of associated grassland species is of serious concern. Approximately 55 species that thrive on grasslands in the U.S. are either threatened or endangered with an additional 728 as candidates for listing (WWFC, 1998). In addition to species loss, more subtle impacts have occurred. For example, heterogeneity in highly developed ecotypic grassland vegetation has been lost (Risser, 1998). Other losses can be linked to poor grazing management, reforestation, and fire suppression (WWFC, 1988). Once prairies are destroyed, restoration requires several centuries (Schramm, 1990); however, for conservation purposes (i.e., soil, water, wildlife, etc.), highly-altered agricultural landscapes can return to a functional conservation state much quicker (>1 year).

On a global scale, the warm-season grasses vary from being dominant, as in the tall grass prairies, to moderate or minor as in the mixed grass prairie of North America. Thousands of species are endemic or partially dependent on warm-season grassland habitat (Coupland, 1979). The tallgrass prairie region in North America has undergone more disruption than any other warm-season grassland biome (Coupland, 1979). Lastly, these habitat losses directly affect the overwintering and nesting of grassland bird populations, which will be discussed in further detail in section II.

C) Agronomic Attributes and Functions of Natives

North American native prairie grasses are perennial, herbaceous, drought-tolerant, bunchgrasses with a high yield potential on a wide range of soil (Parrish and Fike, 2005). These species are suitable for soils considered marginally economical for annual row crops and can improve soils by protecting them from erosion and increasing their C storage, aggregation, infiltration, and water-holding capacity. Native grasses generally grow 1–3 m tall and roots of established plants may reach depths of 3-m (McLaughlin et al., 1999; Vogel et al., 2002; Weaver, 1954). These native perennials, particularly switchgrass are known to have high water- and nutrient-use efficiencies, Appendix 4. Meaning they produce relatively high amounts of biomass per unit of water transpired and per unit of essential-nutrient uptake (Heaton et al., 2004). Typical of most native grasses, they are warm-season grasses, meaning they fix CO_2 by the C_4 photosynthetic pathway (Moss et al., 1969). This pathway enables the plant to tolerate high summer temperatures and moderate-high drought stress. Optimum temperature for C_4 photosynthesis is between 35 to 38ºC (Long, 1999). Generally, warm-season C_4 grasses require about one-third to one-half as much water and nitrogen to produce a unit of dry matter, compared to C_3 grasses e.g., tall fescue (Moser et al., 2004).

Native species have a reputation for being difficult or slow to establish (Moser and Vogel, 1995; Parrish and Fike, 2005). As they allocate a large amount of energy to developing strong root systems, these species generally accumulate little above-ground growth in Year 1; typically attaining only 33 to 66% of the maximum production capacity during the first and second years before reaching its maximum yield potential (McLaughlin and Kszos, 2005). Harvestable or significant biomass accumulates in Year 2, reaching maximum yields in Year 3 and beyond (Casler et al., 2007; McLaughlin and Kszos, 2005). During their vegetative phase, the rate development is closely related to accumulated growing-degree days (GDD), while timing of reproductive development is tied to photoperiod (Parrish and Fike, 2005).

Due to the increased usage of NWSG in production systems (i.e., forage and biofuel), production costs and establishment efficiencies have greatly improved, However, despite work done by the NRCS Plant Materials Center and native grass seed producers, on a per unit land area basis it is still more expensive to plant native grasses compared to exotic sod-forming forage crops (e.g., seed for switchgrass \$4.5 PLS kg^{-1}, compared to \$2.2 for entophyte-positive tall fescue). Therefore, private landowners that are interested in planting native species responsible for conserving water and protecting soil from erosion are in need of monetary assistance in order to compensate for production costs.

II. ECOLOGICAL BENEFITS PROVIDED BY NATIVE GRASSES

A) Role of Native Grasses in facilitating wildlife habitat

Endemic grass morphology and physiology promote tolerance to both drought and herbivory, the latter is specifically important for insects (Schooler et al., 2009), invertebrate populations (Gottwald and Adam, 1998), and mammals (Clark et al., 1999); as they prefer the canopy structure provided by native species. These ecological functions were widely provided by native bunchgrasses until the promotion of sod-forming grasses.

Native species sustain wildlife populations. Native grasslands are arguably the most threatened ecosystem, and as a result several associated species such as grassland birds, have declined. In order to conserve grassland communities, restoration, or re-vegetation must occur and provide adequate resources required by wildlife populations. Native grasses provide cover, act as a food source, and provide material/structure for nesting/bedding that cannot be provided by forbs alone. Nesting substrate, structure, and nutrients for nestlings and chicks are particularly important for grassland bird reproduction and largely provided by prairie grasses.

Habitat loss is considered the primary cause of population decline for the most popular upland game bird, the northern bobwhite (*Colinus virginianus*) in the eastern United States (Sorrow and Webb, 1982). Some of the loss is attributed to converting farmland to other land uses; however, the majority of the decline is from the conversion of native grasslands to exotic forages, such as tall fescue and bermudagrass. The habitat quality of tall fescue and bermudagrass are poor considering they form a dense sod, lack sufficient bare ground, and do not provide structure required for nesting, feeding, or brood rearing (Burger, 2005; Stoddard, 1931). Additionally, many endemic species do not prefer exotic cool-season grasses such as tall fescue and generally lose weight or do not reproduce if forced to consume it (Madej and Clay, 1991).

Breeding bird survey (BBS) routes between 1966 and 2002 indicated that 3 out of 28 species significantly increased; whereas 17 decreased (Sauer et al. 2003). Grassland bird population decline in the 20th century is the partial result of habitat loss due to intensive agricultural practices, such as land conversion and subsequent cultural practices e.g., mowing height and frequency, crop accessions (e.g., sod-forming invasive forages), and inputs (herbicide, pesticide, and insecticide), thereby causing nest and brooding destruction (Bollinger and Gavin, 1989; Jones and Vickery, 1997). However, the Conservation Reserve Program has funded the planted of both native bunchgrasses and introduced sod-forming grasses. As identified by the Endangered Species Act (U.S. Fish and Wildlife Service 2002), the four major threats to the continental grassland bird populations are i) conversion of native grasslands (i.e., breeding grounds) to agriculture, ii) destruction of nests by certain agricultural practices, iii) historical conversion of native grasslands on wintering grounds; and, iv) rangeland management (standardized grazing).

Changes in land use can have greater impacts on habitat quality than changes in management practices (Miranowksi and Bender, 1982). Establishment of grassland species greatly impacts wildlife populations, especially in areas that have been converted to annual row crop or sod-forming agriculture. Replacing annual crops with perennial grasses can provide stable cover and food resources for wildlife.

B) Native Species Impact on Insect Populations

Native plants grown on a large-scale whether for conservation plantings, cellulosic bioenergy, or forage, have the potential to increase arthropod populations, which will likely increase the presence of higher tropic-level species. Because grasslands provide habitat for predators; increasing these habitats could potentially decrease the need for biological and chemical control (Bianchi et al., 2006; O'Rourke et al., 2011). As a result, indirect effects could occur throughout the food web since arthropods provide food for organisms such as birds and mammals.

Native bunchgrasses are often planted in 'conservation strips,' which increase predator, prey, and parasitoid numbers. Conversely, non-native sod-forming grass species may pose a threat to other sensitive crops by acting as a bridging host for pests (Huggett et al., 1999). Biodiversity conservation has recently focused on promoting pollinator species for the preservation of threatened species in fragmented ecosystems, such as tallgrass prairies. Additionally, the loss of native, wild, insect pollinators is impacting numerous agricultural crops, thereby having significant economic implications (Kevan and Phillips, 2001). Bumble bee (*Bombus Latreille*) diversity in tallgrass prairie patches is influenced by resources in the landscape, especially in grasslands. Hines and Hendrix (2005) found that nesting provided by, and around prairie bunchgrasses are important for maintaining bumble bee diversity and may be used as a predictor of species' abundance. Overall, high-diversity, native grass systems have greater pollinator and species richness compared to introduced sod forming grass systems (Gardiner et al., 2010).

III. HERBACEOUS SOD-FORMING AND BUNCHGRASS IMPACTS ON WATER QUALITY

INTRODUCTION

Grasslands are key to an efficient hydrologic cycle, as the quantity and quality of water runoff and infiltration is directly linked to the surrounding ground cover. Perennial grasses both consisting of the sod-forming and bunchgrass growth habit have the ability to reduce overland flow in addition to filter sediment and agricultural chemical byproducts when planted adjacent to waterways. However, the nuances between native and exotic sod-forming grass soil and water conservation effectiveness is not definitively understood; therefore, the purpose of this paper is to compare the ability of these two assemblages for their ability to reduce soil erosion, increase nutrient/sediment retention, reduce water-flow velocity, and waterway stabilization in the coming two sections. For the purposes of this paper, riparian buffer, riparian zone, buffer strip, filter strip, and vegetated filter strip are terms used synonymously and are linear, contour grass strips adjacent to waterways. Lastly, for a complete meta-analysis encompassing the next two chapters see Appendixes 9 &10 for abbreviated study listing (Melcher and Skagen, 2005).

There is a large body of evidence that native bunchgrasses play a crucial role in stabilizing stream banks and wetland areas by promoting soil stability and filtering sediment-bound compounds, as the density of their stems and roots is high (Appendix 5). This is especially important during periodic flooding, as it is suggested that most native grasses, especially switchgrass, can withstand continuous immersion for up to 60 days (Gamble and Rhoades, 1964) (see Appendix 6 for a summary of damage to various grasses under flooding conditions).

Native grasses can serve as vegetative filter strips or buffers and can be used for phytoremediation by increasing the sorption of pesticides and nutrients [specifically nitrogen (N) and phosphorus (P)] carried in runoff that would otherwise be deposited into neighboring groundwater systems (Dillaha et al., 1989). Buffer strips, or strips of herbaceous vegetation, are extremely important in maintaining water quality, especially when adjacent to row crop agricultural fields. Native bunchgrasses also improve wildlife habitat, channel stabilization, and their presence can reduce water temperatures, thereby benefiting fish populations. Moreover, the U.S. Environmental Protection Agency (U.S. EPA) considers N and P among the top stressors in aquatic ecosystems (U.S. EPA 2002). Excess phosphorus in ground water systems can cause eutrophication, resulting in increased algal growth. As the algae dies, it consumes biological dissolved oxygen, resulting in fish kills and loss of biodiversity (Vitousek et al. 1997). Major sources of P and N include fertilizers or animal manures from agriculture. However if adequate herbaceous vegetation exists within the flowpath, water infiltration can increase and water turbulence can decrease; thereby, reducing non-point source pollution by providing a physical barrier. Native bunchgrasses have proven to prevent the transport of such pollutants from fields into neighboring water systems.

NATIVE BUNCHGRASS VS. INTRODUCED SOD-FORMING GRASS EFFECTIVENESS FOR IMPROVING WATER QUALITY

Vegetative filters composed of cool-season and warm-season grasses have the potential to greatly reduce runoff, sediment, and sediment-bound pollutants; however, there is increasing evidence that native perennial bunchgrass species may have a greater potential for sediment deposition and uptake/ removal. While many studies have validated that perennial bunchgrasses have the ability to reduce sediment-bound pollutants in water systems, the ability of different species to reduce sediment loads and promote infiltration is not well known. For our purposes, water quality is demarcated as a body of waters suitability for its intended use based on its chemical, biological and physical characteristics.

Dillaha et al. (1989) suggested that short, sod-forming cool-season grasses lose their ability to be effective filters because they become inundated with sediment more quickly than those of native perennial bunchgrasses. Additionally, Dabney et al. (1993b) verified that warm-season bunchgrasses, such as switchgrass, have a high tolerance to sediment loads and can, therefore, remain effective filter strips for extended periods of time. For this reason some riparian forest buffer conservation practice standards, such as those in Iowa (Code 392-USDA-NRCS, 1997), now require twice the width for cool-season grasses sod-grasses compared to warm-season bunchgrasses.

The low growing habits of tall fescue and bermudagrass may provide inadequate protection when surface water velocities are high (Dabney et al. 1993a). Taller, erect bunchgrasses, such as switchgrass are reportedly more suitable filter strips (Dabney et al. 1993b). Similarly, big bluestem (*Andropogon gerardii*) and eastern gamagrass (*Tripsacum dactyloides*) are erect, tall, warm-season, perennial bunchgrasses and, therefore, have the ability to slow water velocities (Lee et al., 1999). This is because the hydraulic resistance of stiff grasses is reportedly greater than that of finer vegetation such as tall fescue and bermudagrass (Dabney et al. 1993a). Additionally, the majority of intense rainfall events occur when warm-season grass growth is at a maximum (spring and summer); whereas, cool-season species growth is minimum or even dormant and, therefore, may not be as physiologically adapted to withstand intense rainfall events.

A few studies have shown that sod-forming forages, such as tall fescue, bermuda and bahia grass may provide equivalent barriers and filtration to water when compared to warm-season native bunchgrasses. A study done by Self-Davis et al. (2003) sought to evaluate the effect of five forage species (switchgrass, big bluestem, bermudagrass, eastern gamagrass, and tall fescue) at varying canopy heights on surface runoff and infiltration on plots fertilized with poultry litter. They found that there was no statistical variation in runoff volumes between canopy heights within a single species; however, full canopies, with the exclusion of bermudagrass, generally reduced runoff volumes. They reported there was no difference in runoff between these five species for any simulated rainfall event; however, infiltration was on average 19% higher in tall fescue plots for all runoff events, compared to the other forage species. Out of all the grasses in this study, bermudagrass was the least effective filter strip. This was reportedly due to bermudagrass having the least extensive root system (i.e., root length and root density) (Self-Davis et al., 2003). Between the two exotic species in this study, tall fescue was significantly more efficient at infiltrating and impeding soil runoff, due to a fuller canopy, higher crown cover, greater root length and root density (Beyrouty et al., 1990; Self-Davis et al., 2003). The results of this study indicate that tall fescue may be more effective at reducing runoff volumes and increasing infiltration compared to the other species under rainfall simulation. However, simulated runoff conditions in early-spring favored the cool-season forage as the warm-season grasses were just breaking dormancy and had produced very little vegetative growth. Therefore, these results might not be completely conclusive due to negligible treatment-date effects as a result of physiological growth-stage variation. Warren et al. (1986) showed that during the dormant season for mixed rangeland species, sediment movement was greater and infiltration rates lower when compared to species' maximum growth periods.

Native bunchgrass buffers commonly trap up to 50% of coarse sediment and significant amounts of nutrients. A simulated rainfall study by Lee et al. (1999) compared the effectiveness of a native warm-season grass (switchgrass) to cool-season filter strips [bromegrasss (*Bromus inermis*), timothy (*Phleum pretense*) and tall fescue] and determined that the switchgrass filter strip removed significantly more total-N, NO_3^--N, total-P, and PO_4^--P than cool-season grass filter strips ($P < 0.05$). This was attributed to a greater presence of leaf litter, which suspended and deposited coarse particles that were then filtered through leaf litter and either taken up by the plant or decayed *en situ* (Lee et al., 1999). Native grasses are known to facilitate microbial breakdown of organic matter, pesticides, and heavy metals by oxygenating nutrients attached to sediments (Dodson, 1999).

A study by Lee et al. (2003) determine the effectiveness of an established switchgrass filter and a switchgrass/woody buffer in reducing runoff, sediment, N, and P from corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] fields during natural rainfall events. Buffers were sized to conform to the Code 393 grass filter and the Code 391 riparian forest buffer standards (USDA-NRCS, 1999a and b).The switchgrass buffer removed 95% of the sediment, 80% of the total-N, 62% of the NO_3^--N, 78% of the total P, and 58% of the PO_4^--P. The switchgrass/woody buffer removed 97% of the sediment, 94% of the total-N, 85% of the NO_3^--N, 91% of the total-P, and 80% of the PO_4^--P in the runoff. For this buffer, combinations of the dense, stiff, native warm-season grass and woody vegetation improved the removal effectiveness for the nonpoint source pollutants from agricultural areas (Lee et al., 2003). Lastly, mechanisms for nutrient removal in this study were infiltration of runoff water into soil profile and sedimentation capture by leaf litter.

Chemical retention is another important characteristic of vegetative filter strips. Mersie et al. (2003) compared switchgrass and tall fescue filter strips for their ability to remove dissolved copper pesticide during two simulated runoff flow rates over a 0.92 m. wide filter strip. At the higher flow rate, total infiltration rates were 21% for soils with no cover, 33% for switchgrass, and 28% for tall fescue. At the slow flow rate, 77%, 97%, and 100% of the applied copper pesticide was removed from no grass, switchgrass, and tall fescue, respectively. Adsorption to soil appeared to be the primary mechanism for heavy metal removal (Mersie et al., 2003). About 60% of the applied copper was removed by both grasses during the higher velocity runoff period, whereas the slower rate helped remove all the copper in the runoff, especially in tall fescue plots. This study also suggests that retention and infiltration rates of different species are greatly affected by water velocities. In another study, Asmussen et al. (1977) determined that bermudagrass effectively reduced 2,4-D (2-4-dicholorphenoxyacetic acid) concentrations in surface runoff water by increasing retention and infiltration into soil when compared to bahiagrass (*Paspalum notatum*) and the control (i.e., no filter).

Rankins et al. (2001) studied the effectiveness of native grasses and tall fescue filter strips for reducing sediment and herbicide losses in runoff. Big bluestem, eastern gamagrass, switchgrass, and tall fescue reduced total runoff volume by at least 55, 76, 49, and 46%, respectively. However, contrary to previous studies, they found that there was no significant difference among any of the perennial grass filter strips in regard to their ability to filter sediment and herbicide. It should be noted that this study planted species in 30-cm wide strips, which is far less than standard recommendations (Dabney 1993a; Dillaha, 1989). Additionally, the method for transplanting varied between cool- and warm-season grasses in the study. For example, tall fescue was transplanted from sod, or a continuous mat; whereas, the native grasses were transplanted from rhizomes, or a single root mass. Therefore, these results may not be representative of actual on-farm practices. In general, this study determined that eastern gamagrass, switchgrass, big bluestem, and tall fescue are all effective filter strips species and reduced sediment flow, runoff, and herbicide loss from nearby cotton by at least 66%, when compared to the unfiltered check. However, previous research indicated that eastern gamagrass is the least tolerant species to herbicide drift, whereas, switchgrass was the most tolerant among all the grasses investigated (Rankins et al., 1999).

Switchgrass vegetative filter strips show promise as a conservation tool for reducing sediment and nutrient loss in runoff and may complement current conservation practices. A study done by Blanco-Canqui et al. (2004) confirmed that switchgrass is an effective alternative or addition to tall fescue filter strips for reducing sediment and nutrients in runoff. In this study, monotypic filter strips of tall fescue and native grass and forb mixtures were equally successful for reducing runoff sediment and nutrients; however, fescue-native species mixtures reduced organic N, NO_3^--N, NH_4^--N, and particulate P better than tall fescue alone (Blanco-Canqui et al., 2004). Lastly, this study demonstrated the effectiveness of the grass treatments for reducing sediment loads increased with the width of the filter strip, but reductions for strips <4 m wide were small (Blanco-Canqui et al., 2004).

Conclusions

Best management practices such as filter strips, grassed waterways, buffers and windbreaks are all eligible for funding under a variety of USDA conservation programs. These programs are intended to reduce soil erosion and its associated adverse impacts on adjacent water bodies. Filter strips are often planted between annual row crop production areas and water systems in order to reduce the sediment load in the surface water runoff. A large body of scientific evidence suggests the current management protocol (e.g., not mowing in nesting season, periodic prescribed burning, etc.) and physiology of native grass may promote habitat for some wildlife species, as well as greatly improve soil and water biochemical functions; as it is known that linear vegetative strips of native bunchgrasses have equivalent benefits for soil and water conservation compared to exotic sod-forming grasses, and based on some studies are more advantageous for water systems. The conservation management techniques described in this section can be found in publications such as the National Handbook of Conservation Practices (USDA-NRCS, 2002) and Dickerson et al. (2004).

Despite the type of land disturbance, changes in the watershed affect aquatic habitat as well as water quality. Changes in the physical property can be caused by channelization, erosion, sedimentation and rehabilitated hydrological regimes. Grassed waterways are generally located in the middle of fields and strategically placed for the prevention of gully erosion; whereas, riparian filter strips allow for stream bank and ditch stabilization, which allows for energy dissipation and the reduction of sediment loads into waterways. Perennial bunchgrasses, particularly natives, have a high filtering capacity for sediments, chemicals and nutrients from neighboring cropping systems at high drainage water velocities. Native bunchgrasses can be used in contour filter strips that can retain 50-70% of nutrients, pathogens, and sediment.

A large body of research states that native perennial bunchgrasses are more efficient (or at least equivalent) at trapping sediment, specifically as they are capable of withstanding summer drought conditions, exhibit maximum growth in tandem with intensive rainfall events (summer), and possess a growth habit that may trap and suspend particles and particle-bound sediment better than non-native sod forming grasses. However, it should be noted that native grass establishment may take up to two years and; therefore, may leave soil partially exposed during the establishment period (up to one year), which may leave upper soil horizons vulnerable to erosion. However, preliminary research is underway by the authors of this paper that confirms the use of nurse crops, such as winter wheat for aiding soil stabilization and weed suppression during the establishment period, thereby negating these adverse effects. Additional efforts that are underway to combat this issue include selecting varieties with less hard seed, as well as the development of more aggressive weed management approaches.

In conclusion, vegetative filter strips composed of perennial sod-forming and bunchgrasses have the potential to greatly reduce runoff, sediment and sediment-bound pollutants. However, the majority of evidence concludes that native warm-season bunchgrasses may have a greater potential for sediment, erosion and runoff control, compared to that of introduced sod-forming grasses, all while providing enhanced wildlife habitat. Between the two major introduced sod-forming forage species, tall fescue is more efficient at reducing sediment flow, runoff, and herbicide loss when compared to bermudagrass, and in some cases may be comparable to native warm-season perennial bunchgrasses. Research is still needed on comparing native and introduced grass species for their use as vegetative filter strips for enhanced water quality at various points in the growing season and under homogenous planting conditions.

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IV. IMPACTS OF SOD-FORMING AND BUNCHGRASSES' ON SOIL CONSERVATION

INTRODUCTION

Soil erosion is a major threat to sustaining long-term crop yields, and sediment deposition in streams is a major threat to aquatic habitats. In the U.S., 72 million acres of cropland were estimated to need erosion control in the late 1970s. Annual estimates of soil losses during this time were 1-2 billion tons yr^{-1} (ASCE, 1977), and by 1987, 3 billion tons (McLaughlin et al., 1999). More recently, conservation programs have reduced this number by ca. 50% (USDA-NRCS, 1997) and it is possible this value could be further reduced given enhanced management practices and proper species selection.

The production of annual row crops enhances the physical loss of soil and the associated nutrients, depletes soil organic carbon (SOC) by aerating soil particles, and reduces stable soil aggregation. For example, when perennial grasses are compared to cultivated annual crops, there are profound economic and ecological differences. Erosion losses associated with corn (*Zea mays* (L.)) are ca. 70 times greater than for the production of grasses on similar land (Shifflet and Darby, 1985). Nationally, ca. $18 billion in fertilizers costs are lost annually to soil erosion (National Research Council, 1993). In addition to monetary reductions, chemical inputs to aquatic systems are high as a result of these losses. Soil organic matter content is greatly reduced by tillage, which has far reaching effects on soil density, aeration, moisture content, and nutrient availability, all of which have been observed from the Northern Plains to the Mid-South

(Aguilar et al., 1988). Losses of soil organic matter (SOM), via tillage of annual row cropping in the U.S. were placed at 2.7 million metric tons per year (CAST, 1992).

In an effort to protect erodible cropland from soil erosion and improve water quality, the Conservation Reserve Program (CRP) was established in 1985 by Congress and total enrolled acreage increased steadily until peaking at 39.7 million acres early this century (Appendix 8), and has been declining since that time. In efforts to offset losses from annual row crop cultivation, much of the 32 million acres of CRP land established in 1985 was planted with perennial grasses, due to their erosion-prevention capacity. However, during that time, native perennial bunchgrasses were not widely included in this program. Nevertheless, comparable if not improved soil and water conservation benefits can be obtained from native species, while providing better wildlife habitat (Burger, 2005). Similarly, NRCS established the National Conservation Buffer Initiative with the goal of assisting landowners in establishing nearly 5 million miles of buffer areas around U.S. waterways (USDA-NRCS, 2002). The primary farm conservation practices that establish new grass fields are CP1 (introduced grasses and legumes) and CP2 (native grasses) and each must be in accordance with the NRCS Practice Standard 327 Conservation Cover (USDA-NRCS, 2002).

CARBON REPLACEMENT VALUE OF INTRODUCED AND NATIVE SPECIES

Agricultural soils can absorb substantial amounts of CO_2 from the atmosphere and store it as organic matter, particularly when growing perennial, no-till crops. From a soil conservation standpoint, perennial grasses are generally more beneficial than exotic sod-forming forage grasses, and significantly greater than annual row crops. Calculated C sequestration rates of bunchgrasses may exceed those of annual crops by up to 20 to 30 times, owing in part to C storage in the soil (McLaughlin and Walsh, 1998). Once established, bunchgrasses can be produced for many years without the cost, soil loss, and degradation of annual replanting. The inputs of organic carbon from high rates of root production and turnover in soils developed under switchgrass and other natives have important implications for improving both the structure and long-term productivity of agricultural soils (Bransby et al., 1998).

Native bunchgrasses are an important terrestrial ecosystem to sequester C, considering they produce only 6% of the global biomass but have 15% of the global soil organic C (Jobbagy and Jackson, 2000), as more than 95% of the C in C_4 grasses is belowground as soil organic matter. The maintenance of living roots and crowns has many benefits including acquisition of nutrients and water from deep in the soil profile, a strong energy storage reserve for rapid spring recovery, stable yields during stress years, and continual soil organic matter formation (McLaughlin and Walsh, 1998). The active pools of roots from native perennial bunchgrasses are major sources of carbon due to fine root turnover, active populations of soil microorganisms, and lower leaf deposition, all which may add up to 3 Mg ha^{-1} yr^{-1} (Lynch and Whipps, 1991). This significant carbon storage capacity of native bunchgrasses greatly increases carbon sequestration rates, soil fertility, and water-holding capacities and infiltration rates, compared to sod-forming species.

One notable feature of native grasses is the litter accumulation, in that approximately 2960 kg C $ha^{-1}y^{-1}$can accumulate (Tufekcioglu et al., 2003), which is of importance as litter insulates the soil and can impede water flow, as well as build SOM, thereby sequestering C and reducing groundwater nitrate levels. A study by Tufekcioglu et al. (2003) measured above and belowground C contributions among poplar (*Populus* × *euroamericana* 'Eugenei'), switchgrass, smooth brome (*Bromus inermis*), timothy (*Phleum pratense* L.),and Kentucky bluegrass (*Poa pratensis* L.) and found that switchgrass produced more live aboveground biomass with higher C-N ratios than did the exotic forage grasses. Similarly, switchgrass had the highest mean aboveground dead biomass, C and N pools. In addition, switchgrass plots contained more aboveground detritus year-round than did any other species in this study. This study also reported that switchgrass had the lowest root and shoot-N concentrations, but the greatest root biomass; as switchgrass had the highest root biomass in both 0–35 and 35–125 cm soil depths. Furthermore, Tilman and Wedin (1991) observed that the species with the greatest root biomass and the lowest root and shoot-N concentrations reduced soil ammonium and nitrate to a lower level than did other species grown in monocultures along an experimental nitrogen gradient. Thus, switchgrass may reduce soil nitrate levels more than introduced forage grasses, thereby preventing the accumulation in water systems. Ma et al. (2000) found that switchgrass has an extensive root system, extending up to 330 cm below the soil surface, Therefore, riparian buffers containing native bunchgrasses, such as switchgrass have the potential to sequester C from the atmosphere and to immobilize N in biomass; thereby slowing or preventing N losses to the atmosphere and to ground and surface waters; implying that native grasses can be useful in preventing nutrient losses associated with non-point source pollution.

A study by Bransby et al. (1998) determined carbon and nutrient retention gains in soils under native perennial grass production. They found that on CRP lands, perennial grasses added ca. 1.1 Mg of C ha^{-1} over 5 yrs, which is about 20% of the SOC lost in previous decades due to tillage. Authors of this study suggest that native warm-season bunchgrasses in production systems, such as switchgrass, could add up to 3 Mg C ha^{-1}, due to the cyclic turn-over of large standing pools of roots, as well as rhizosphere deposition from the plant (Bransby et al., 1998); which is higher than that of introduced forage species (Sanderson et al., 2004). Research done by Garten and Wullschleger (2000) stated that there is more coarse root C in soils under switchgrass production than under tall fescue, ranging from 23.8 to 58.7 and 2.5-18.5 mg C cm^{-2}, respectively.

Conversely, one study compared pasture grasses at the 0-75 cm depth and found that soil organic carbon did not vary greatly in tall fescue and switchgrass grass pastures (D.J. Parrish, unpublished data). Values were 1.24, 1.28, 1.34 and 1.38% for fallow, tall fescue, \`Alamo' switchgrass and \`Cave-in-Rock' switchgrass plots, respectively. Only the highest and lowest of these values differed significantly ($P < 0.05$). Mean soil bulk density for a 1-3 cm depth was lower for tall fescue than for \`Cave-in-Rock' switchgrass. Investigators concede the lack of variation could be a function of shallow sampling depth (Bransby et al., 1998). When compared at greater depths, native warm-season grass roots are significantly more massive than those of introduced species (Appendices 5 & 7, and carbon sequestration rates are reportedly greater (Lynch and Whipps, 1991; McLaughlin and Kszos, 2005).

NATIVE BUNCHGRASS VS. INTRODUCED SOD-FORMING GRASS EFFICIENCY AT SOIL CONSERVATION

Stiff bunchgrass hedges may reduce water-soil erosion such as sheet, rill, or gullies (Sanderson et al., 1995) and help prevent N and P losses in surface water and encourage sedimentation. Warm-season bunchgrasses, such as vetivergrass (*Vetiveria zizaniodes* (L).) and switchgrass reportedly work best as hedges as their stems and stubble are stiff and strong enough to hold back water and their deep root system prevents slope failure (Grimshaw and Helfer, 1995). Also, stiff grasses for barriers can slow the spread and flow of erosive water runoff by causing runoff to pond. The erosive energy is further reduced by infiltration within the barrier. Sod-forming grasses (e.g., tall fescue) seemingly do not possess the mechanical strength to pond, or slow water because their canopy collapses under extreme water pressure and concentrated flow channels form (Lee et al., 1998).

Bermudagrass has proven to be less effective at trapping particles and reducing erosion when compared to warm-season natives or tall fescue, but may prove to be more useful than other introduced warm-season species and bare, fallow soils. Research in the Southeast demonstrated significant reductions in soil loss from three tillage systems with the use of a bermudagrass filter strip (Raffaelle et al., 1997). However, it should be noted that once introduced to a site, bermudagrass has the potential to compete with adjacent crops due to its aggressive growth habit (Miller, 1998).

There is evidence that switchgrass can remediate soils, as well as continue growth under adverse growing conditions. A greenhouse phytoremediation study by Cofield et al. (2007) investigated the potential dissipation and plant translocation of polycyclic aromatic hydrocarbons by tall fescue and switchgrass 3, 9 and 12 months after exposure. In this study, switchgrass produced more root biomass than fescue after 9 and 12 months of exposure ($P < 0.05$) (Appendix 7). Additionally, shoot growth after 12 months was greater for switchgrass than tall fescue. Furthermore, the switchgrass rhizosphere removed/ stored significantly greater amounts of hydrocarbons than did that of tall fescue.

Research in Iowa with forage grasses as part of a multi-species riparian buffer system showed that switchgrass functioned better than exotic cool-season grass filter strips for soil conservation. This was likely due to the production of larger amounts of leaf litter, and because switchgrass has stiffer stems, a stronger and more dense root system (Appendix 5), and a growth habitat that is more erect and uniform than cool-season grasses (i.e., bromegrass, timothy, and tall fescue) (Lee et al., 1999). Switchgrass filter strips have also proven to effectively reduce herbicide concentrations in surface runoff water by preventing soil loss and increasing water retention and infiltration (Mersie et al., 1999).

Studies on soil erosion, chemical runoff, and nutrient retention provided by native grasses support the theory that native bunch grasses can greatly improve SOC and reduce erosion and chemical runoff (Lynch and Whipps, 1991; Bransby et al., 1998). However there are some studies that indicate that exotic cool-season grasses may provide equivalent conservation benefits, such as soil stabilization, chemical retention, and upper horizon organic matter formation. However, at greater depths, native warm-season grass roots have significantly greater mass than those of introduced species and may actually build soil by greatly contributing to the soil organic carbon pool (McLaughlin et al., 1999).

CONCLUSIONS

The growth habit of perennial bunchgrasses facilitates many components of soil conservation. Deep, well-developed root system can result in comparable below-ground biomass to that of aboveground vegetation, which is particularly true of native bunchgrasses (Appendices 5 & 7). Their extensive root system has many benefits including acquisition of nutrients, water and more stable yields and persistence during stress years, as well as increased soil organic carbon (SOC). These attributes are key to soil conservation as they can reduce soil erosion, conserve water and nutrients, and reduce the runoff of sediment and agrochemicals. Vegetation type and physiological growth pattern affect the stabilization, water infiltration, and carbon building capacity of the soils they occupy.

Vegetative cover determines hydrologic processes that in turn affect infiltration, soil runoff, soil-water storage, and soil physical properties. If soils are left bare during intense rainfall events, the dislodging of soil particles may occur, and nutrients in the soil solution may exit the soil profile (Bransby et al., 1998). The high level of resource allocation to root production; while slowing above-ground growth during establishment is key to many of the desirable conservation attributes of native bunchgrasses post-establishment (McLaughlin and Kszos, 2005). However because of this, vegetative growth is slow during the establishment period and; therefore, leaf area index and A-horizon soil coverage is low, which may result in increased soil erosion control when compared to introduced species during the establishment period (up to one year). However, this can be mitigated by using a nurse crop which will aid in soil stabilization, thereby negating these adverse effects (P.D. Keyser, unpublished data).

In general, most studies indicate that, in the short term, native and non-native perennial grass filter strips stabilize soil and remove similar amounts of sediment; however, when compared long-term, the effectiveness of non-natives decreases because they become inundated with sediment, thus reducing their effectiveness to stabilize soil (Dillaha et al., 1989). Additionally, introduced sod-forming grasses may offer less long-term effectiveness than native warm-season grasses to stabilize and build soil, due to lesser amounts of litter production, non-erect and stiff stems, and relatively shallower, less coarse root systems. Therefore, bunchgrasses buffer strips have the ability to spread the overland flow and increase infiltration while reducing the depth of water flowing across the surface (Lee et al., 1998). In the process, coarse particles are suspended and filtered through the soil.

Warm-season perennial bunchgrasses are valuable components of soil and water conservation practices as they prevent wind erosion and enhance soil stabilization and phytoremediation, particularly in riparian zones (Sanderson et al., 2004). Introduced forage species, specifically tall fescue, may have the ability to stabilize soil under non-extreme rainfall events in the short term. However, when compared at greater soil depths and over longer time periods, native warm-season grasses are likely to have a greater soil-building capacity, carbon sequestration, nutrient retention, and infiltration/purification capabilities. Quantitative data on performance of various species' ability to stabilize soil under more extreme flow rates and during different physiological stages of species are still needed.

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SUMMARY AND CONCLUSION

Land use changes have precipitated steep declines for pollinator and wildlife populations; however, converting perennial cool-season or highly erodible land acreage to native grass may have far reaching ecological impacts. Native grasses are often endorsed for conservation plantings (specifically for species in decline, i.e., early successional and pollinator populations), as they provide desirable wildlife habitat needed for nesting. Grassland birds are experiencing severe and sustained (>40 years) declines, more so than any other group of birds, making this among the most intractable challenges in contemporary conservation. Habitat loss is considered the primary cause of population decline for the most popular upland game bird, the northern bobwhite. Native bunchgrasses promote soil and water conservation, as well as wildlife habit, as a diversity of natives can provide better food, cover, and over-wintering habitat for wildlife compared to non-native species. The introduction of sod-forming grasses in the eastern landscape of the U.S. has greatly caused severe and long-term population declines in associated grassland wildlife.

No other biome made up of warm season grasslands have undergone more disruption than the tall grass prairie region in North America, with <4% of this native vegetation remaining (Sanderson et al., 2004). Native grasses have recently commanded more serious attention for multiple uses, especially among wildlife, cellulosic biofuels, and forage producers and managers. Along with this attention, much research has been conducted to improve establishment success of natives, and with consorted efforts, native grasses can be successfully established and used for their intended purpose be it for forage, conservation, or bioenergy. Native bunchgrasses are a viable option for landowners interested in promoting conservation, sustainable biomass production, or economically profitable forage production.

Due to the wide range of native grasses, high yield with low inputs (nutrients and pesticides), and their potential for dual use as both a forage and biofuel species, there has been increased interest for their use as model feedstocks (McLaughlin and Walsh, 1998). Natives have the added benefit of being suitable for growth on 'marginal' soils or soils considered 'marginally' economical for annual row-crop production. Natives can provide an abundance of high-quality forage when forage from cool-season species is inadequate. Also, the production and use of native plants for cellulose-derived ethanol can potentially reduce greenhouse gas emissions because the C released as CO_2 during combustion is re-assimilated into the subsequent year's regrowth of the biomass crop, which could offset CO_2 emissions to the atmosphere. It is feasible that these warm-season forages and/or lignocellulosic biomass agroecosystems could be part of environmental solutions while providing income for rural farmers.

Species of the sub-humid prairies and humid savannas of North America also have been promoted by the CRP, due to their drought tolerance, noninvasiveness, potential for soil carbon sequestration, and soil and water protection. Once established, native grasses perennial growth pattern eliminates annual soil disturbance and thus, the risk of soil erosion. Unless new and more aggressive conservation programs are initiated, some of the warm-season bunchgrasses planted as part of the CRP may go back to row-crop agriculture or sod-forming grassways when current contracts expire. USDA commodity programs may indirectly support conversion of grassland to cropland because they include crop insurance, marketing loans and disaster assistance; farmers can expand their eligibility to receive these benefits by converting grassland species to exotic cropland (Claassen et al., 2011). Finally, the environmental costs and benefits of growing native grasses can be measured in terms of the relative effects on preventing soil erosion and the movement of agro-chemicals into water systems and by providing wildlife habitat for populations in decline.

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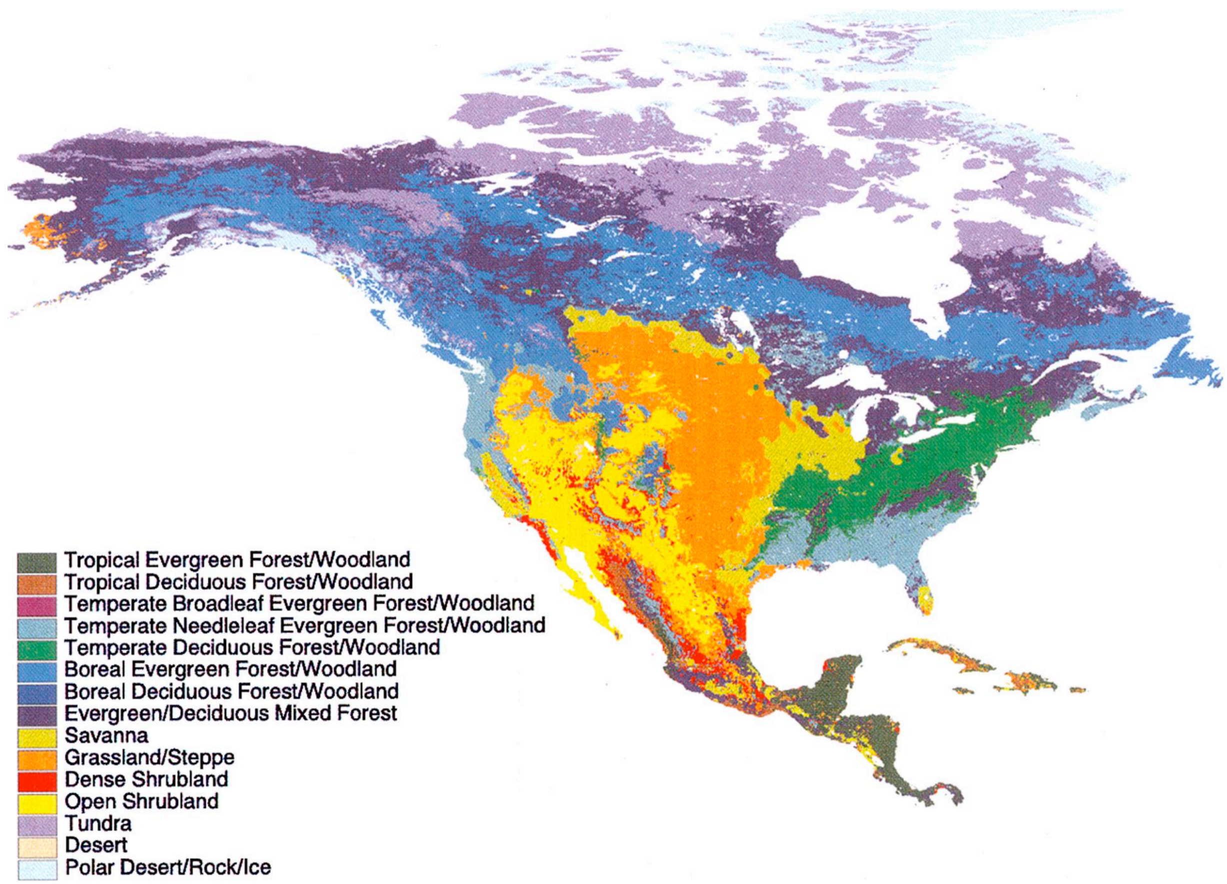
APPENDIX

Appendix 1.

Potential vegetation types at a resolution of 5 min. These data are derived by using the DIScover land cover data set with the regions dominated by land use filled by using Haxeline and Prentice vegetation data set (1996). Data source: Ramankutty and Foley (1999)

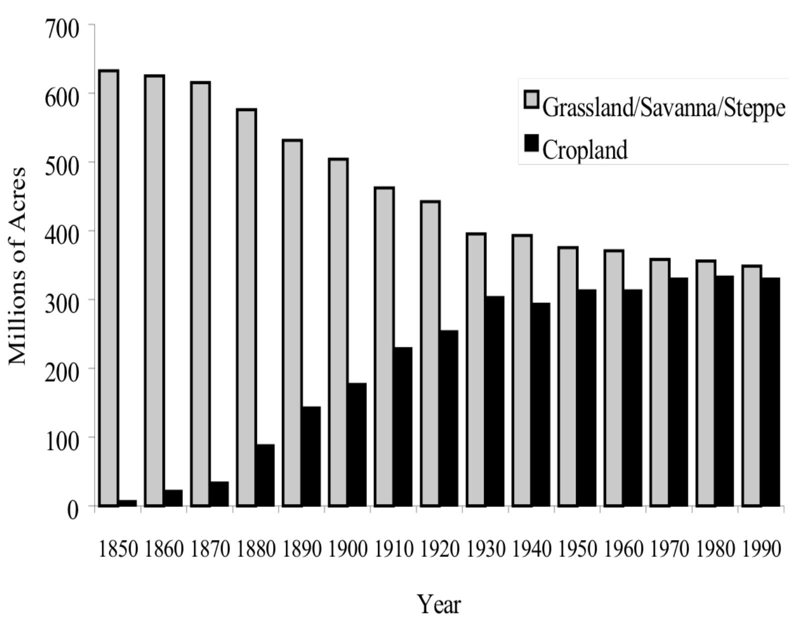


Appendix 2.
Selected native grass species described throughout the paper.

Species	
Common name	***Scientific name***
Big bluestem	*Andropogon gerardii*
Little bluestem	*Schizachyrium scoparium*
Broomsedge	*Andropogon virginicus*
Indiangrass	*Sorghastrum nutans*
Switchgrass	*Panicum virgatum*
Eastern gamagrass	*Tripsacum dactyloides*
Sideoats grama	*Bouteloua curtipendula*
Inland sea oats	*Chasmanthium latifolium*
Virginia wildrye	*Elymus virginicus*

Note: not a complete list of native species described in this paper; just selected ones intended as examples.

Appendix 3.
Estimated land cover of native Grassland/ Savanna/ Steppe compared to Croplands in the U.S. west of the Mississippi River, 1850-1990. Data source: Ramankutty and Foley (1999).



Appendix 4.

Water-use efficiency (WUE, g dry wt. kg^{-1}) of forage groups and individual species. (References are listed below the table).

Forage Group	Species	WUE, g kg^{-1}	Reference
Legume	Alfalfa	1.75-3.01	1-4
	Birdsfoot trefoil	2.5	5
	White clover	1.26	6
Cool-Season perennial grasses	Reed canary	3.0	7
	Tall fescue	2.04	8
	Perennial ryegrass	1.46-2.61	8,9
Warm-Season perennial grasses	Switchgrass	3-5	10, 11
	Indiangrass	2.6	11
	Bermudagrass	1.05-2.50	12

(1) Rechel et al., 1991
(2) Guitjens and Goodrich, 1994
(3) Carter and Sheaffer, 1983
(4) Bolger and Matches, 1990
(5) Carter et al., 1997
(6) Nijs et al., 1989
(7) Barker et al., 1989
(8) Johnson and Basset, 1991
(9) Stout, 1992
(10) Cox et al., 1988
(11) Kinry et al., 2008
(12) Martin and Gazaway, 2003

Appendix 5.

Native, warm-season grass root system relative depths compared to exotic turf grasses such as bermudagrass and Tall fescue.

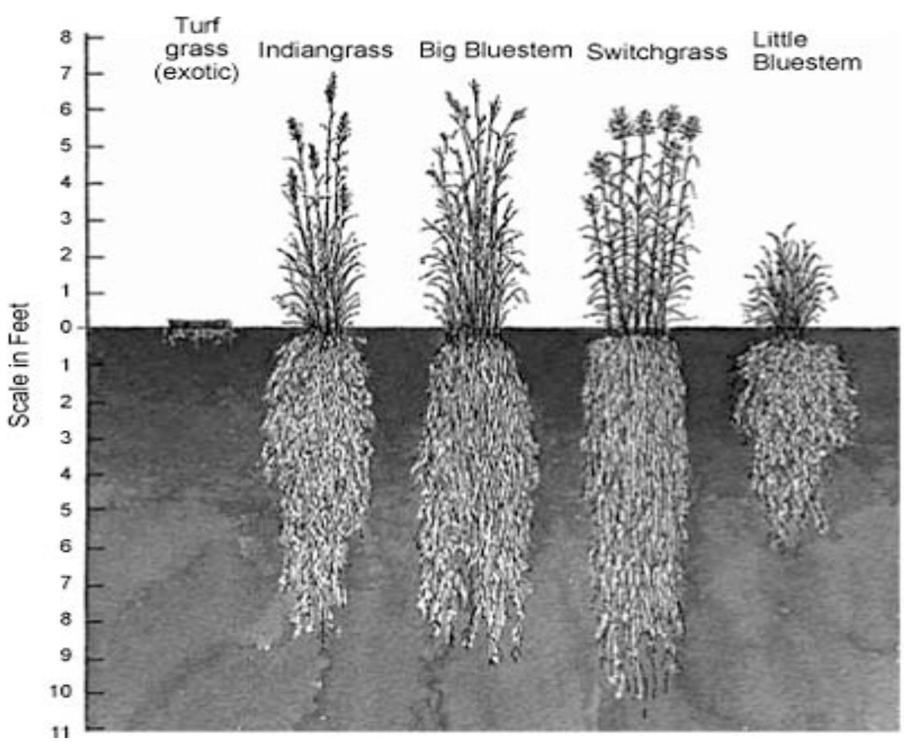


Illustration by: Dede Christopher of the Tenneesee Valley Authority, 'Benefits of Riparian Zones'.

Appendix 6.

Summary of damage to selected grasses under varying depths and durations of flooding during early spring, midspring, and late spring. Data source: Gamble and Rhoades (1961).

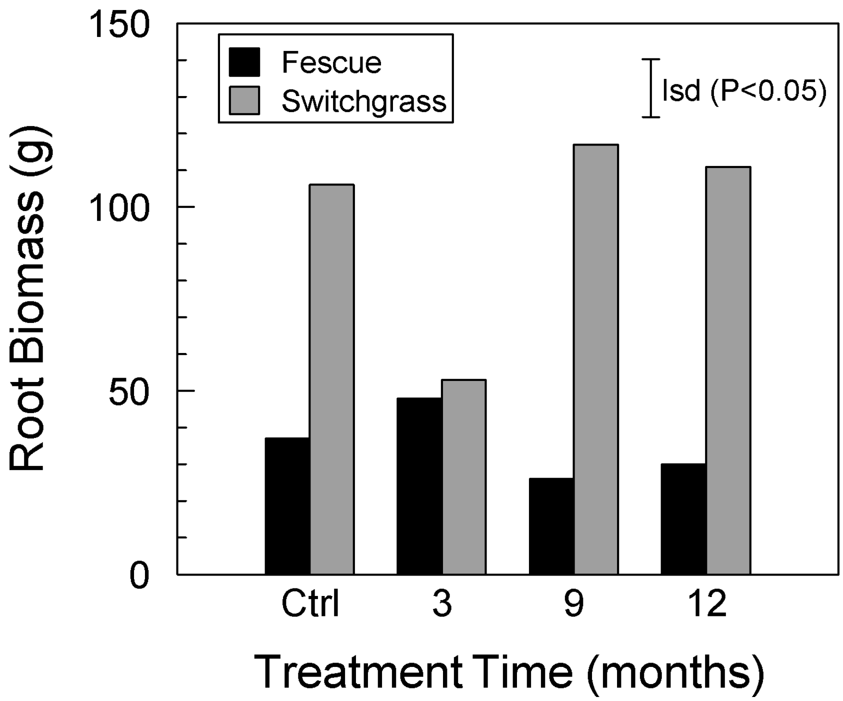
Grass*	Flooding depth, ft.	Extent of damage† by basin no., flooding duration, and season‡: 6		1			5		2			4	3	
		5_2	5_3	5_1	5_2	5_3	10_2	10_3	10_1	10_2	10_3	20_2	20_1	20_2
1. Common bermuda-grass	0-2	A	A	A	A	A	A	A	A	A	A	A	A	A
	2-4	A	A	A	A	A	A	A	A	A	B	B	A	B
	4-6	A	A	A	A	B	A	B	A	A	B	B	A	B
2. Buffalo-grass	0-2	A	A	A	A	A	A	A	A	A	A	A	A	A
	2-4	A	A	A	A	A	A	A	A	A	B	B	A	B
	4-6	A	A	A	A	B	A	B	A	A	B	B	A	B
3. Vine mesquite	0-2	A	A	A	A	A	A	A	A	A	A	A	A	A
	2-4	A	A	A	A	A	A	A	A	A	A	A	A	A
	4-6	A	A	A	A	A	A	B	A	A	B	A	A	A
4. Prairie cordgrass	0-2	A	A	A	A	A	A	A	A	A	A	A	A	A
	2-4	A	A	A	A	A	A	A	A	A	A	A	A	A
	4-6	A	A	A	A	A	A	B	A	A	B	B	A	B
5. Kanlow switch-grass	0-2	A	A	A	A	A	A	A	A	A	A	A	A	A
	2-4	A	A	A	A	A	A	A	A	A	A	A	A	A
	4-6	A	A	A	A	A	A	B	A	A	B	B	A	B
6. Caddo switch-grass	0-2	A	A	A	A	A	A	A	A	A	A	A	A	A
	2-4	A	A	A	A	A	A	A	A	B	B	B	A	B
	4-6	A	A	A	B	B	B	B	A	B	C	D	A	D
7. Kaw big bluestem §	0-2	A	A	A	A	A	A	A	A	B	C	C	A	C
	2-4	A	A	A	A	B	B	C	A	C	D	D	A	D
	4-6	A	C	A	B	B	C	D	A	C	D	D	A	D
8. Eastern gamagrass	0-2	A	A	A	A	A	A	B	A	A	B	B	A	B
	2-4	A	A	A	B	B	A	B	A	B	C	C	A	D
	4-6	A	B	A	B	C	B	C	A	C	D	D	A	D
9. Alkali sacaton	0-2	A	A	A	A	A	A	B	A	A	B	B	A	B
	2-4	A	B	A	A	B	B	C	A	B	C	C	A	C
	4-6	B	B	A	B	C	B	C	A	C	D	D	A	D
10. Elkan bluestem	0-2	A	A	A	A	A	A	B	A	B	C	C	A	C
	2-4	A	A	A	B	C	B	D	A	D	¶	D	A	D
11. Weeping lovegrass	0-2	A	A	A	A	A	A	B	A	B	B	C	A	C
	2-4	A	B	A	A	B	B	D	A	C	D	D	A	D

* Technical names of grasses: 1. Cynodon dactylon, 2. Buchloe dactyloides, 3. Panicum obtusum, 4. Spartina pectinata, 5. Panicum virgatum var., 6. Panicum virgatum var., 7. Andropogon gerardi var.) 8. Tripsacum dactyloides, 9. Sporobolus airoides, 10. Andropogon ischaemum var., 11. Eragrostis curvula.

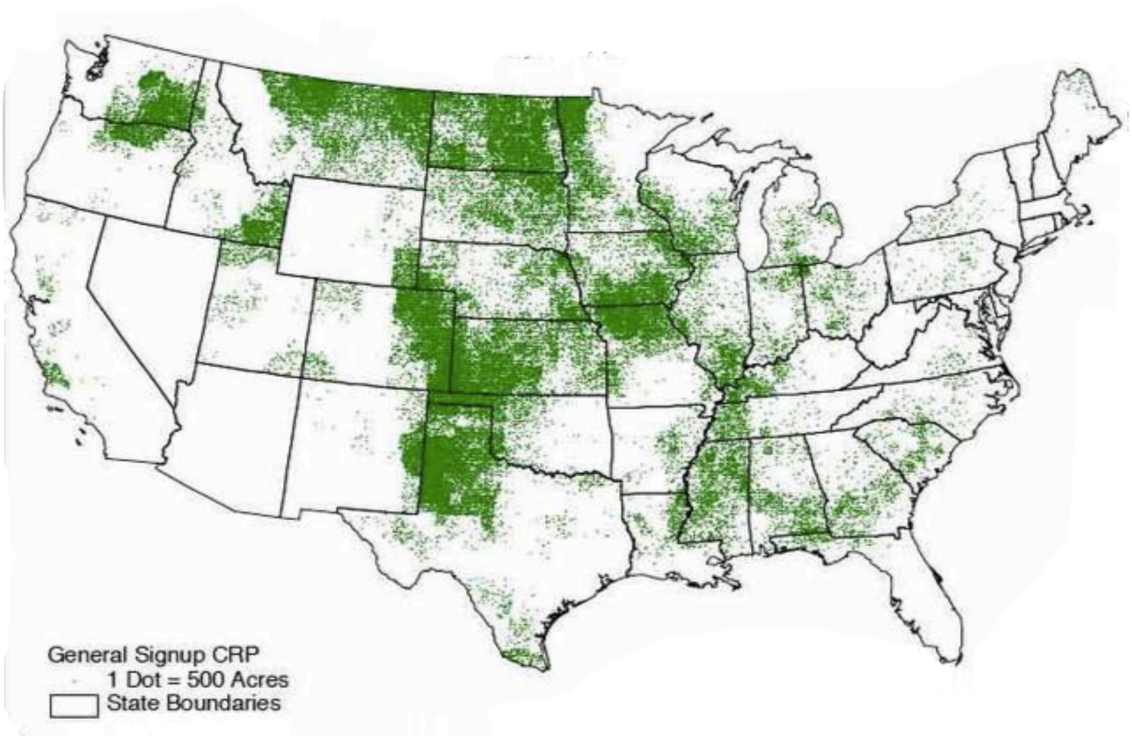
† A = No damage, or slight temporary damage including slight to moderate suppresion of growth. Very little discoloration and no killing of any part of the plant. B = Moderate to severe killing of top growth of individual plants, with an occasional plant killed. C = Majority of plants killed. D = All plants killed. ‡ Duration refers to days and subscript to season of flooding; for example, 5_1 means flooded for 5 days during early spring, 5_2 means floowed for 5 days during midspring.

§ *Flooding tolerance of Woodward sand bluestem was slightly less than Kaw big* bluestem. ¶ All plants at this depth were killed during previous flooding.

Appendix 7.
Plant root biomass (dry weights) for planted treatments of fescue and switchgrass (at 3-12 months). Data source: Cofield et al. (2007).



Appendix 8.
Conservation Reserve Program general signup in the U.S., as of April, 2004. Data source: USDA, NRCS. This map was provided by: FSA/DAFP.CEPO.



Appendix 9.
Accronyms used to describe studies in Appendix 10. Data source: US Dept. of Interior, USGS. Available at: http://www.fort.usgs.gov/Products/Publications/21485/21485.pdf

BCR = Bird Conservation Region
BMP = best management practice
CRP = Conservation Reserve Program
DN = dissolved nitrogen
DNTE = dissolved nitrogen-trapping efficiency
DP = dissolved phosphorus
DPTE = dissolved phosphorus-trapping efficiency
GW = grassed waterways
HTE = herbicide-trapping efficiency
N = nitrogen
NRCS = Natural Resource Conservation Service
NTE = nitrogen-trapping efficiency
OP = organophosphate
P = phosphorus
PLJV = Playa Lakes Joint Venture

PLR = playa lakes region
PTE = phosphorus-trapping efficiency
SHP = Southern High Plains
STE = sediment-trapping efficiency
TSS = total suspended solids
UN = undissolved nitrogen
UNTE = undissolved nitrogen-trapping efficiency
UP = undissolved phosphorus
UPTE = undissolved phosphorus-trapping efficiency
VFS = vegetated filter strip
WR = water retained/infiltrated

Appendix 10.

Abbreviated summary of selected buffer studies on design and effectiveness of buffers or vegetated filter strips for trapping sediment, nitrogen, phosphorus, and herbicide, adapted from: US Dept. of Interior, USGS. Available at:
http://www.fort.usgs.gov/Products/Publications/21485/21485.pdf

Author, year	Region	Crop[a]; tillage type[b]	Buffer design[c]	Buffer effectiveness[c]	Notes[c]
Abu-Zreig and others (2004)	Ontario, Canada	N/A	VFSs in experimental field plots 2, 5, 10, 15 m wide; slopes 2.3, 5%; VFS species perennial ryegrass/ fescue, trefoil/ creeping red fescue, bare, native riparian vegetation (incl. wild oat, quack, fescue, dandelion, other); tests of STE, WR.	Ave. STE = 84% (in trefoil/creeping red fescue range = 68% & 98% in 2- & 15-m VFS, respectively; 25% in control); little improvement beyond 10 m, indicating width threshold for STE. WR = 20% & 62% in 2-m & 10-m VFSs, respectively. For 5-m filters, WR = 47% in native, 40% in trefoil/creeping red fescue; WR greater in native due to greater % cover. Greater antecedent soil-moisture content = decreased WR.	Soil type = silt loam (38% sand, 54% silt, 8% clay); varied antecedent soil-moisture; simulated runoff representing short/intense events over 2-10 yrs; increasing runoff flow rate decreased STE.
Barfield and others (1998)	Kentucky	NT, CV in the year prior to study; no crop grown during study	VFSs of naturally occurring bluegrass/ fescue sod; VFSs 4.57, 9.14, 13.72 m wide in 4.57 X 22.1 m field plots at 9% slope. VFSs 1-yr old; tests of STE, NTE, PTE, HTE.	Overall effectiveness >than reported elsewhere in similar plots & on gentler slopes-–probably due to significant infiltration in karst soils, even when saturated. STE, NTE, PTE, HTE increased with >buffer width, although difference between 4.57- & 9.14-m buffers was not significant; overall buffer efficiency >90% for sediment and pollutants. Overall reductions in pollutants attributed more to infiltration than soil adsorption.	Simulated 2 10-yr rainfall events. Region dominated by karst soils underlain by limestone (i.e., >>macropore structure, infiltration capacity) at significant slopes; included here to provide a sharp contrast to conditions of the PLR. Rainfall applied only upslope of buffers (not on buffers).
Castelle and others (1994)	N/A	N/A	Buffer review. Authors identified 4 criteria for assigning buffer width: the protected resource's functional value, intensity of land-use in the watershed, buffer characteristics, specific buffer purpose.	Buffers 3-200 m. Effectiveness for a given width varied according to conditions; overall, buffers of ≥15 m usually needed under most conditions. Narrower buffers needed when: buffer in good condition (native vegetation, undisturbed soils), wetland severely damaged/of low value, watershed has low-impact land-use. Wider buffers needed when: valuable/functional wetlands are threatened, watershed receives intensive land-use, when buffer in poor condition.	This is a literature review of buffer effectiveness. Overall, flow rates lower when sheeting over even surface, greater when channelized. Buffers remove nutrients and metals through plant uptake, infiltration, settling of suspended solids.

Dillaha and others (1986)	Various, mostly e. US	N/A	Review of numerous studies in experimental & field plots, all VFS. Focus on STE, NTE, PTE.	STE generally ≥90% for larger sediments & <40% for clay <1 m if flow was even & shallow; wider VFSs needed for finer particles, deeper flow. VFSs tended to become inundated by sediments at upslope flanks, diminishing effectiveness. DPTE & DNTE = generally >50 <70% in VFSs <1 to 36 m, but some studies show no difference between controls & VFS plots.	Includes literature review & Virginia VFS specs. VFS management emphasized. If VFS in good shape, overall STE overall excellent for sand- to silt-sized particles, less for clay. PTE and NTE of VFSs less effective, even in VFSs ~30-36 m, partly due to chemical changes of N % P in VFS resulting in later release of N, P.
Dillaha and others (1989a)	Virginia	N/A	VFSs ~3-9 m, mostly tall fescue. Field evaluations of real-world buffers.	33 farms were visited; 76% had functional buffers being used for the intended purpose, but nearly 100% were damaged by fully erosion, thus largely ineffective. Some were also damaged by cattle trampling, farm equipment, lack of maintenance.	This was a field evaluation of actual VFSs installed on farms. The authors provide installation and maintenance recommendations, although some may unsuitable for the PLR.
Dillaha and others (1989b)	Virginia	CV	VFSs 4.6, 9.1 m wide in field plots; slope 5-16%; tests of STE, NTE, PTE.	Significantly more STE, NTE, PTE in plots w/ VFS, all three increasing with filter width. STE = 70-84% (ave. 70%), NTE = 54-73%, PTE = 61-79%. Percent N and P reduced closely corresponded with sediment reduction, as most N & P were sediment-bound. After subsequent rainfalls, sediment-bound P & N began dissolving, volitalizing (gaseous state), & were released at levels high enough to cause eutrophication in buffered wetland. On 5% slopes, VFSs absorbing concentrated flows generally as effective as those w/ even flows, & more effective than VFSs absorbing even flows on 16% slopes; similar trends observed for P & N. Concentrated flows had proportionately smaller volumes of sediments by the time they had concentrated, thus sediment volume not necessarily greater in concentrated flows.	Silt loam soils. N & P applied, then rainfall simulated at 50 mm/hr 4 times over one week (200 mm); runoff in even sheetflow or concentrated in drainageways. Most sediment deposited just upslope, or in first few meters, of the VFSs. As sediments buried VFS upper flanks, they spilled downslope to the next section until that was buried; VFSs became less effective with each new rainfall; may not be a problem in real watersheds if vegetation can grow up through accumulated sediments.
Eghball and others (2000)	Iowa	CV, NT; CR	6-yr. old single switchgrass hedges, 0.75 m wide planted in 6-ha field plots. Applications of commercial fertilizer & manures on no-till and disked plots with varying levels of corn residue; tests of NTE and PTE.	NTE & PTE were significantly greater with than without hedges, but they may have been more effective on slopes <12%. More P ran off from manure fields than those treated w/ commercial fertilizer, although a smaller % of applied P was lost from manure fields. More N ran off fertilized fields. Overall, hedges were effective in reducing N to acceptable levels; but DPTE was still higher than desired.	Ave. slope = 12% (range 8-16%) w/ silt loam soils. Rainfall (6.4 cm/hr for 2 hrs.) was simulated. Residue cover in no-till plots was 51-94% (ave. 79%), 11-58% on disked plots (ave. 34%).
Gilley and others (2000)	Same as above	Same as above	Same as above	Where water ponded deeply, runoff began to filter unevenly through the hedge. In no-till plots, runoff and soil loss was 52 & 53% less, respectively, from plots w/ corn residue & hedges than from plots w/ no residue & hedges; in disked plots, runoff and soil loss was 22 & 57% less in plots w/ residue & hedges than in from plots with no hedges. In disked plots w/ hedges but no residue, runoff and soil loss were 41 & 63% less in plots w/ no hedges or residue.	This was another part of the study listed above. STE was reported in tons/ha rather than the more-typical %, making comparisons with this study difficult. Runoff was measured in mm. It underscores the need to use hedges in conjunction with other BMPs.
Komor and Hansen (2003)	Minne-sota	N/A	VFSs to reduce runoff at 2 feedlots: 35 cattle, 225 cattle.	Pollutant reduction ranged widely due to variation in season, soil-moisture, extent of matting of filter grasses. DNTE = 14-75%, UNTE & organic N = 29-82%, UPTE = 24-82%, DPTE = 14-72%. Also, reductions of: 6-79% dissolved chloride, -3-82% dissolved sulfate, 33-80% dissolved ammonia N (>>volitalized or taken up by plants), 30-81% of the chemical oxygen demand, and 18-79% fecal coliform bacteria (also killed by exposure to sunlight).	Affects of cattle # not mentioned explicitly, but results similar at both feedlots/VFSs. Ground water compromised by infiltration of pollutants from VFSs. Primary means of pollutant reduction believed to be interception by plants & soil, but also by infiltration & plant uptake.
Lee, K.-H. and others (1999)			VFSs 3 and 6 m wide (ratios of watershed to VFS = 40:1 & 20:1, respectively), planted w/ switchgrass, smooth brome, timothy, and/or fescue; tests of STE, NTE, PTE.	6-m STE = 77%, NTE = 46%, DNTE = 42%, PTE = 52%, DPTE = 43%. 3-m STE = 66%, NTE = 28%, DNTE = 25%, PTE = 37%, DPTE = 34%. Overall, 6-m VFSs significantly more effective. Switchgrass VFSs significantly more effective at removing N, DN, P, DP than cool-season grasses.	Simulated rainfall at varying intensity/duration. Ave. slopes 3%.

Magette and others (1989)	Mid-Atlantic coastal plain		VFSs of fescue 4.6 & 9.2 m wide in field plots (5.5 X 22 m); tests of STE, NTE, PTE.	Overall, increasing ratio of VFS area to unvegetated (runoff) area increased VFS effectiveness. VFSs had better STE than NTE or PTE; overall effectiveness for all NTE/PTE diminished w/ subsequent rainfall events. NTE in 4.6-m VFSs was poor, likely because soluble N is transported easily in terrestrial systems; possible lower threshold of VFS width, below which N cannot be removed effectively. Most P bound to sediment, thus transport generally occurs w/ suspended solids; if VFS has high STE, it should have high PTE.	Simulated rainfall applied; bare source areas tilled 2X during 12 tests of varying antecedent moisture conditions/rainfall intensities; nutrient sources = liquid N v. chicken manure. Results varied widely, partly due to 'flushing' events where mass losses of built-up material suddenly occurred.
Mickelsen and Baker (1993)			VFSs 4.6 & 9.1 m wide; tests of STE.	STE = 72 & 76%, respectively.	Lower STE that that in Dillaha and others (1989b) probably due to greater sediment volumes in runoff in this study.
Robinson and others (1996)	Iowa		VFSs on slopes 7 & 12% in field plots, 18.3 m of tilled fallow as runoff source, 18.3 m VFS of brome (w/ some alfalfa, orchard-grass); tests of STE.	STE of first 3 m = 70%, 85% in 9,1 m, w/ most sediment having been trapped by 9.1 m; nonlinear relationship. Runoff and sediment losses greater on 12% slopes.	Silt loam soils, natural rainfall. Storm intensity (rainfall amount) affected width at which maximum STE was achieved.
Schmitt and others (1999)	East-central Nebraska	N/A	Filter strips 7.5 & 15 m wide; tests of STE, HTE, NTE, PTE; in field plots of grain sorghum, soybeans; some strips contained shrubs, trees.	Doubling VFS width 7.5 to 15 m doubled infiltration, dilution. Herbicide reduced mostly by dilution from rainfall; infiltration reduced runoff 36-82%.	Slopes ranged 6-7%, soils were silty clay loam.
Seybold and others (2001)	N/A	N/A	VFSs planted w/ switchgrass 125 cm high (at tillering stage) in tilted beds (0.9 X 3 m) at 1% slope; tests of HTE for atrazine and metolachlor.	Overall HTE in VFS plots = 68.5-73%, in bare plots = 52.9-57.9%. Infiltration/ leaching was primary means of HTE; at all soil depths, microbial activity degraded herbicides continuously over 7-week study; degradation rates were greater in VFSs than in bare strips, significantly for metolachlor. Dissolved herbicide in surface runoff reduced by soil & plant adsorption greater in bare plots (6.2-6.4%) than VFS plots (5.3-5.4%). Infiltration 56% in bare strips, 82% in VFSs. (Infiltration in sandy loams is likely to occur at a steadier rate, but overall infiltration predicted to be greater in clay loams; however, infiltration in clay loams may be reduced by cracks that can form during wet-dry cycles; see Vervoort and others (1999.) Two of three VFSs precluded all runoff; ave. runoff from bare plots = 33%.	Clay loam soil. Herbicides tested commonly used on corn. Switchgrass selected due to stiff stalk that resists high water velocities, deep root system capable of soil-holding, has minimal water/nutrient requirements. HTE depends on soil type/texture, vegetation type, slope, antecedent soil-moisture, rainfall, macropores, etc. Roots of switchgrass may degrade metolachlor more efficiently than atrazine, but half-life of atrazine may be 2.5-4 times longer. Mersie and others (1999) found that switchgrass VFSs removed significantly more atrazine and metolachlor than bare strips; Tingle and others (1998) found significantly more metolachlor was removed by fescue VFSs than bare strips. In field settings, switchgrass thatch buildup expected to enhance adsorption.
Tingle and others (1998)	Missis-sippi	SB; CV	VFSs of 0.5, 1, 2, 3, 4 m wide in 4 X 22 m field plots planted w/ tall fescue, clipped to 10 cm at start of growing season for 3 yrs; tests of HTE for metolachlor & metribuzin.	HTE = 48-68% 2 d after application, regardless of VFS width; more metolachlor removed than metribuzin. After 84 d, more herbicide lost in every plot, but reductions in VFS plots higher than in controls, & 4-m plots overall had best HTE. Cumulative sediment & runoff reduction = 83 & 46%, respectively, width not significant..	Silty clay soil. 2 days after first herbicide treatment 83-93% water runoff reduced, regardless of width; 46–77% reduction of water over growing season. Both metolachlor & metribuzin highly soluble.
Wilson (1967)	Arizona		VFSs 167.5 & 305 m wide in field plots 0.3 and 4.54 acres, respectively; slopes .6 and .1 %, respectively; 3 yrs.; tests of STE & WR w/in flood periods.	VFSs effective for STE of sand, silt, and clay (inverse relationship between STE of particle size & VFS width). STE greatest in first 15.4 m, but depths continued to increase up through ~121 m. Overall STE = 60–95%, generally better in Bermudagrass.	VFSs = fescue, switchgrass, Bermudagrass, Sudan grass, or alfalfa (>1 variety of switchgrass, orchardgrass, Bermudagrass). Max. sand STE at 3.5 m, silt at 15.4 m, and clay at 91.5 m. Overall, grass not inhibited by deposits; Bermudagrass esp. able to 'climb' out of sediments.

Crops: CR = corn; CT = cotton; SB = soybean; WW = winter wheat; IR = irrigated; DR = dryland farming
Tillage: CV = conventional; NT = no-till
DN = dissolved nitrogen
DNTE = dissolved nitrogen-trapping efficiency
DP = dissolved phosphorus
DPTE = dissolved phosphorus-trapping efficiency
HTE = herbicide-trapping efficiency
NTE = nitrogen-trapping efficiency
PTE = phosphorus-trapping efficiency
STE = sediment-trapping efficiency
UN = undissolved nitrogen
UNTE = undissolved nitrogen-trapping efficiency
UP = undissolved phosphorus
UPTE = undissolved phosphorus-trapping efficiency
WR = water retained/infiltrated