

Growing Switchgrass for Biofuels

Switchgrass (*Panicum virgatum*) is a native warm-season grass that is a leading biomass crop in the United States. More than 75 years of experience with switchgrass as a hay and forage crop suggest switchgrass will be productive and sustainable on rain-fed marginal land east of the 100th meridian. Long-term plot trials and farm-scale studies in the Great Plains and plot trials in the Great Plains, Midwest, South, and Southeast indicate switchgrass is productive, protective of the environment, and profitable for the farmer. Weed control is essential during establishment but with good management is typically required only 2 or 3 times every 10 years. Although stands can be maintained indefinitely, stands are expected to last at least 10 years, after which time the stand will be renovated, and new, higher-yielding material will be seeded on the site. Fertility requirements are well understood in most regions, with about 10 pounds of N per acre required for each ton of expected yield if the crop is allowed to completely senesce before the annual harvest. Switchgrass is well suited to marginal cropland and is an energetically and economically feasible and sustainable biomass energy crop with currently available technology.



A second year stand of 'Liberty' switchgrass in eastern Nebraska. This dryland field grew over 3 tons per acre in the seeding year in 2012, and 8 tons per acre in 2013. Photo: Rob Mitchell

CenUSA Researchers:

Rob Mitchell is a research agronomist with USDA-ARS and a professor of Agronomy at the University of Nebraska-Lincoln. His role in CenUSA is analyzing both the agronomic potential and environmental impacts of promising bioenergy crops and management systems using a network of fourteen fields strategically located across the Central U.S. **Ken Vogel** is a research geneticist with USDA-ARS and a professor of Agronomy at the University of Nebraska-Lincoln. His role in CenUSA is developing perennial grass cultivars and hybrids that can be used on marginal land in the Central U.S. for the production of biomass for energy. **Marty Schmer** is a research agronomist with USDA-ARS and an associate professor of Agronomy at the University of Nebraska Lincoln.

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Introduction

Grassland scientists have conducted research on switchgrass (*Panicum virgatum*) for more than 75 years, with initial research focusing on livestock and conservation. In 1936, L. C. Newell, an agronomist with the Bureau of Plant Industry, USDA, in Lincoln, Nebraska, began working with switchgrass and other grasses to potentially re-vegetate large areas of the central Great Plains and Midwest that had been devastated by the drought of the 1930s. The first switchgrass cultivar from this program was Nebraska 28 which was jointly released by USDA and the University of Nebraska in 1949. Since that time, establishment and management practices have been developed and refined, genetic resources have been evaluated, seed production has been improved, and a wealth of information has been made available to producers.

Despite 75 years of research history, most of the general public first heard about switchgrass on January 31, 2006, when President George W. Bush in his State of the Union Address said,

“We must also change how we power our automobiles. We will increase our research in better batteries for hybrid and electric cars, and in pollution-free cars that run on hydrogen. We’ll also fund additional research in cutting-edge methods of producing ethanol, not just from corn, but from wood chips and stalks, or switchgrass. Our goal is to make this new kind of ethanol practical and competitive within six years.”

Interest in switchgrass increased exponentially following the President’s address with attention given to its ability to reduce our dependence on foreign oil and fossil fuel emissions, boost rural economies, reduce erosion on marginal cropland, and enhance wildlife habitat.

Current Potential for Use as a Biofuel

Switchgrass has excellent potential as a bioenergy feedstock for cellulosic ethanol production, direct combustion for heat and electrical generation, gasification, and pyrolysis. The U.S. Department of Energy (USDOE) Bioenergy Feedstock Development Program selected switchgrass as the herbaceous model species for bioenergy because it is a broadly adapted native to North America, it has consistently high yield relative to other species in varied environments, it requires minimal agricultural inputs, it is relatively easy to establish from seed, and a seed industry already existed (McLaughlin and Kzsos, 2005; Parrish and Fike, 2005; Sanderson et al., 2007).

Biology and Adaptation

Switchgrass is a perennial warm-season grass that is native to most of North America except for areas west of the Rocky Mountains and north of 55°N latitude (Figure 1). Because of physiological differences, warm season grasses are more productive during the hotter mid summer months versus cool season grasses (i.e. bluegrass or brome grass) that grow best in cooler, moist periods of the year. Switchgrass has high yield potential on marginal cropland and will be productive in most rain-fed production systems east of the 100th meridian (Vogel, 2004). Productive switchgrass stands can be grown west of the 100th meridian with irrigation (Biofuels Cropping Systems Research and Extension, Washington State University). Switchgrass is adapted to

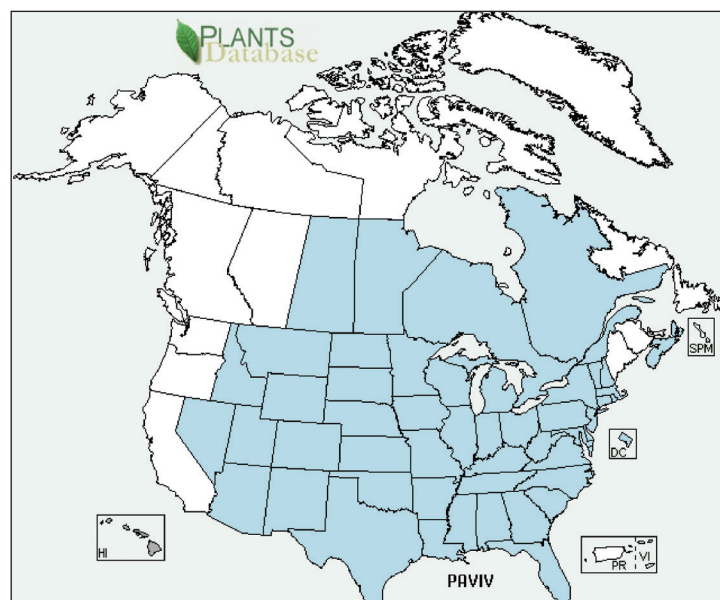


Figure 1. Switchgrass is adapted to much of North America.
Image: USDA NRCS

a wide range of habitats and climates and has few major insect or disease pests. Root depth of established switchgrass may reach 10 feet, but most of the root mass is in the top 12 inches of the soil profile. In addition to potential bioenergy production, switchgrass uses include pasture and hay production, soil and water conservation, carbon sequestration, and wildlife habitat.

Switchgrass has distinct lowland and upland ecotypes. Upland ecotypes occur in upland areas that are not subject to flooding, whereas lowland ecotypes are found on floodplains and other areas that receive run-on water (Vogel, 2004). Generally, lowland plants have a later heading date and are taller with larger and thicker stems. Plant breeders have increased yield of switchgrass by 30-50% through cross breeding lowland and upland ecotypes (Vogel and Mitchell, 2008). These hybrids are promising sources for high-yielding bioenergy cultivars.

Steps to Establishing a Successful Stand of Switchgrass

Successful stand establishment during the seeding year is mandatory for economically viable switchgrass bioenergy production systems (Perrin et al., 2008). Weed competition is the major reason for switchgrass stand failure. Acceptable switchgrass production can be delayed by one or more years by weed competition and poor stand establishment (Schmer et al., 2006).

In the central Great Plains, switchgrass can be planted two or three weeks before to two or three weeks after the recommended planting dates for corn (*Zea mays*), typically from late April to early June. Switchgrass should be seeded at 30 pure live seed (PLS) per square foot (5 PLS pounds per acre) based on the quality of the seedlot. Excellent results are obtained by planting after a soybean (*Glycine max*) crop using a properly calibrated no-till drill with depth bands that plant seeds 0.25 inch to 0.5 inch deep followed by press wheels (Figure 2). Row spacing for switchgrass is typically 6 to 10 inches. No-till seed into soybean stubble or clean-tilled field and pack firmly enough to leave a faint footprint in the soil when you walk on it (Figure 3). If tillage is used, prepare the seedbed as you would for alfalfa.

Manage weeds in switchgrass with a pre-emergent application of 1 quart of atrazine plus 8 ounces per acre of quinclorac (Paramount®). On big bluestem, indiangrass, and sideoats grama, use a pre-emergent application of 4 ounces per acre of imazapic (Plateau®). Control broadleaf weeds in the seeding year by mowing in July and/or spraying with one to two quarts per acre of 2,4-D. After the establishment year, a successfully established switchgrass stand requires limited herbicide applications. Always read and follow label directions.



Figure 2. Soybean stubble provides an excellent seedbed for no-till seeding switchgrass. During the establishment year, all harvests must occur after a killing frost to avoid damaging stands. In the establishment year, good weed management and rainfall will provide about half of the fully established yield potential of the site and cultivar. Photo: Rob Mitchell.



Figure 3. Seeding into corn or sorghum stubble may require plowing, disking, and packing to develop a firm seedbed. Pack the tilled soil until walking across the field leaves only a faint footprint to ensure good seed-to-soil contact and prevent soil in-filling of the packer wheel depression. Photo: Rob Mitchell.

Nitrogen (N) fertilizer is not recommended during the planting year since N will encourage weed growth, increase competition for establishing seedlings, increase establishment cost, and increase economic risk associated with establishment if stands should fail (Mitchell et al., 2008). Soil tests are recommended prior to planting. Since switchgrass is deep rooted, soil samples should be taken from each 1-foot increment to a depth of 5 feet. In most agricultural fields, adequate levels of phosphorus (P) and potassium (K) will be in the soil profile. If warranted by soil tests, P and K can be applied before seeding to encourage root growth and promote rapid establishment. Recommended P levels for the western corn belt are in Table 1. Switchgrass can tolerate moderately acidic soils, but optimum seed germination occurs when soil pH is between 6 and 8 (Hanson and Johnson, 2005). With good weed management and favorable precipitation, a crop equal to about half of potential production can be harvested after frost at the end of the planting year, with 75 to 100% of full production achieved the year after planting.

Soil Test Levels			
P Index Value	Bray & Kurtz #1	Olsen P (Na HCO ₃)	P Rate
	----- ppm -----	lb P ₂ O ₅ /Acre	
Very low	0-5	0-3	40
Low	6-15	4-7	20
Medium	16-25	8-14	10
High	25+	15+	0

Table 1. Phosphorus (P) recommendations for the western corn belt based on two common soil test levels (Anderson and Shapiro, 1990).

Fertilizing Established Stands

Although switchgrass can survive on low fertility soils, it does respond to fertilizer, especially N. The amount of N required by switchgrass is a function of the yield potential of the site, productivity of the cultivar, and other management practices being used (Vogel et al., 2002). A general N fertilizer recommendation for the Great Plains and Midwest region is to apply 20 lb N per acre per year for each ton of anticipated biomass if harvesting during the growing season, with N rate reduced to 10 lbs N per acre per year for each ton of anticipated biomass if harvesting after a killing frost. The N rate can be reduced when the harvest is after a killing frost because switchgrass cycles some N back to roots during autumn. If soil tests indicate a new switchgrass field has high residual N levels, N rates can be significantly reduced during the initial production years using the above information as a guideline. Apply N at switchgrass green-up to minimize cool-season weed competition.

Harvest and Storage

In the Great Plains and Midwest, maximum first-cut yields are attained by harvesting switchgrass when panicles are fully emerged to the post-anthesis stage (~1 August). Sufficient regrowth may occur about one year out of four to warrant a second harvest after a killing frost. Do not harvest switchgrass within six weeks of the first killing frost or shorter than a 4-inch stubble height to ensure translocation of storage carbohydrates to maintain stand productivity and persistence. Dormant season harvests after a killing frost will not damage switchgrass stands but will reduce the amount of snow captured during winter. In general, a single harvest during the growing season maximizes switchgrass biomass recovery, but harvesting after a killing frost will ensure stand productivity and persistence, especially when drought conditions occur, and reduce N fertilizer requirements. Delaying harvest until spring will reduce moisture and ash contents, but yield loss can be as high as 40% compared with a fall harvest (Adler et al., 2006). New bioenergy-specific lowland-based switchgrass like 'Liberty' grown north of 40° north latitude should be harvested after complete senescence in autumn. With proper management, productive stands can be maintained indefinitely and certainly for more than 10 years.

Harvesting switchgrass in summer at or after flowering when drought conditions exist is not recommended.

Switchgrass can be harvested and baled with commercially available haying equipment. Self-propelled harvesters equipped with a rotary head (disc mowers) have most effectively harvested high-yielding (>6-ton per acre) switchgrass fields (Figure 4). Additionally, after a killing frost, the multidirectional arrangement of the switchgrass in the windrow was easier to bale than the linearly arranged windrow left by a sickle-bar head. Round bales tend to have less storage losses than large square bales (>800 lb) when stored outside, but square bales tend to be easier to handle and load a truck for transport without road width restrictions (Figure 5). After harvest, poor switchgrass storage conditions can result in storage losses of 25% in a single year. In addition to storage losses in weight, there can be significant reductions in biomass quality, and the biomass may not be in acceptable condition for a biorefinery. Switchgrass grown for use in a biorefinery may have to be stored for a full year or longer since biorefineries will operate 365 days a year. Some type of covered storage will be necessary to protect the producer's investment.

Potential Yield

Switchgrass yield is strongly influenced by precipitation, fertility, soil, location, genetics, and other factors. Most plot and field-scale switchgrass research has been conducted on forage-type cultivars selected for other livestock-based characteristics in addition to yield. Consequently, the forage-type cultivars in the Great Plains and Midwest are entirely represented by upland ecotypes which are inherently lower yielding than lowland ecotypes. Thus, yield data comparing forage-type upland cultivars like Cave-In-Rock, Shawnee, Summer, and Trailblazer do not capture the full yield potential of switchgrass and are not fair comparisons. For example in Nebraska, high-yielding F1 hybrids of Kanlow and Summer produced 9.4 tons per acre per year, which was 68% greater than Summer and 50% greater than Shawnee (Vogel and Mitchell, 2008). Liberty, a new biomass-type switchgrass cultivar with a 3-year average yield of 8.1 tons per acre, is in the release process and will be available for planting certified seed fields in 2014. Knowing the origin of a switchgrass cultivar is important since switchgrass is photoperiod sensitive. Planting a switchgrass cultivar too far north of the cultivar origin area (>300 miles) can result in winter stand loss. Planting a switchgrass cultivar south of its origin area results in less biomass because the shorter photoperiod causes plants to flower too early.

Environmental and Sustainability Issues

Sustainable biomass energy crops must be productive, protective of soil and water resources, and profitable for the producer. Numerous studies have reported that switchgrass will protect soil, water, and air quality; provide fully sustainable production systems; sequester C; create wildlife habitat; increase landscape and biological diversity; return marginal farmland to production; and increase farm revenues (McLaughlin and Walsh, 1998; McLaughlin et al., 2002). Switchgrass root density in the surface 6 inches is two-fold greater than alfalfa, more than three-fold greater than corn, and more than an order of magnitude greater than soybean (Johnson et al., 2007). In a five-year field study conducted on 10 farms in Nebraska, South Dakota, and North Dakota, Liebig et al. (2008) reported that switchgrass stored large quantities of C, with four farms in Nebraska storing an average of 2,590 pounds of soil organic C (SOC) per acre per year when measured to a depth of 4 feet. However, they noted that SOC increases varied across sites, and the variation in SOC change reiterated the importance of long-term environmental monitoring sites in major agro-ecoregions.

Energy produced from renewable carbon sources is held to a different standard than energy produced from fossil fuels, in that renewable fuels must have highly positive energy values and low greenhouse gas emissions. The energy efficiency and sustainability of ethanol produced from grains and cellulose has been evaluated using net energy value (NEV), net energy yield (NEY), and the ratio of the biofuel output to petroleum input [petroleum energy ratio (PER)] (Schmer et al., 2008). An energy model using estimated agricultural inputs and simulated yields predicted switchgrass could produce greater than 700% more output than input energy (Farrell et al., 2006). These modeled results were validated with actual inputs from multi-farm, field-scale research to predict energy output. Switchgrass fields on 10 farms in Nebraska, South Dakota, and North Dakota produced 540% more renewable energy (NEV) than nonrenewable energy consumed over a

five-year period (Schmer et al., 2008). The estimated on-farm NEY was 93% greater than human-made prairies and 652% greater than low-input switchgrass grown in small plots in Minnesota (Tilman et al., 2006). The 10 farms and five production years had a PER of 13.1 and produced 93% more ethanol per acre than human-made prairies and 471% more ethanol per acre than low-input switchgrass in Minnesota (Schmer et al., 2008). Average greenhouse gas (GHG) emissions from switchgrass-based ethanol were 94% lower than estimated GHG emissions for gasoline (Schmer et al., 2008). Switchgrass for bioenergy is an energetically positive and environmentally sustainable production system for the Great Plains.

Implementing switchgrass-based bioenergy production systems will require converting marginal land from annual row crops to switchgrass and could exceed 10% in some regions depending on the yield potential of the switchgrass strains. In a five-year study in Nebraska, the potential ethanol yield of switchgrass averaged 372 gallons per acre and was equal to or greater than that for no-till corn (grain + stover) on a dry-land site with marginal soils (Varvel et al., 2008). Removing 50% of the corn stover each year reduced subsequent corn grain yield, stover yield, and total biomass. Growing switchgrass on marginal sites likely will enhance ecosystem services more rapidly and significantly than on more productive sites.

Feasibility

Perennial herbaceous energy crops provide several challenges. A stable and consistent feedstock supply must be available year-round to the ethanol or power plant. For the producer, perennial herbaceous energy crops must be profitable, they must fit into existing farming operations, they must be easy to store and deliver to the plant, and extension efforts must be provided to inform producers on the agronomics and best management practices for growing perennial herbaceous energy crops. However, perennial herbaceous energy crops have potential for improvement, and they present a unique opportunity for cultural change on the agricultural landscape.

There are numerous environmental benefits to perennial herbaceous cropping systems that can improve agricultural land use practices such as stabilizing soils and reducing soil erosion, improved water quality, increased and improved wildlife habitat, and storing C to mitigate greenhouse gas emissions. There is large potential for achieving all of these benefits, provided agronomic, genomic, and operational aspects of perennial herbaceous cropping systems are fully developed and accepted by farmers. Herbaceous perennial energy crops may be used in conjunction with agriculture residues (corn stover and wheat straw), which likely would be harvested in autumn, and perennial grasses could be harvested in very early spring while they are dry, similar to when prairies are typically burned. This



Figure 4. Rotary head mowers (disc mowers) effectively harvested this 6-ton per acre switchgrass field. Additionally, after a killing frost, the multidirectional arrangement of the switchgrass in the windrow was easier to bale than the linearly arranged windrow left by the sickle-bar head. Photo: Rob Mitchell.



Figure 5. Proper storage of switchgrass bales is imperative to maintain total harvested dry matter and prevent spoilage. Large square bales can spoil from the top and bottom and can lose more than 25% of total dry matter in six months when stored outside in the open (top left), but covering the large square bales with hay tarps (top right) reduces dry matter loss to about 7% in six months. Wrapping big round bales with at least three wraps of net-wrap maintains the structure of the bale and reduces the surface area of the bale that contacts the ground. Covering big round bales stored outside can reduce dry matter loss to less than 3% in six months. Photo: Rob Mitchell.

may help reduce the need for feedstock storage by providing feedstock at different times during the year.

Growing seed to meet potential demand for bioenergy will not be an issue. Switchgrass has many desirable seed characteristics and can produce viable seed during the seeding year, especially under irrigation. Established seed production fields can produce 500 to 1,000 pounds of seed per acre with irrigation, and the seed is easily threshed, cleaned, and planted with commercial planting equipment. Seed production systems are well established (Cornelius, 1950), and a commercial industry for switchgrass seed has existed for over 50 years.

Summary

Contrary to popular belief, switchgrass is not a new or novel crop but has more than 75 years of research and farming experience. Currently available plant materials and production practices can reliably produce five tons per acre in the central Great Plains and Midwest. New cultivars and management practices will significantly increase yields similar to the yield increases achieved in corn in the last 30 years. The availability of adequate acres of agricultural land and the profit potential provided to farmers for growing switchgrass in a region will determine the success of growing switchgrass for biomass energy. Production practices and plant materials are available to achieve sustainable and profitable biomass production, for both farmers and bio-refineries, to help meet the energy requirements of the nation and reduce our dependence on foreign oil.

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