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# Planting and Managing Switchgrass as a Biomass Energy Crop

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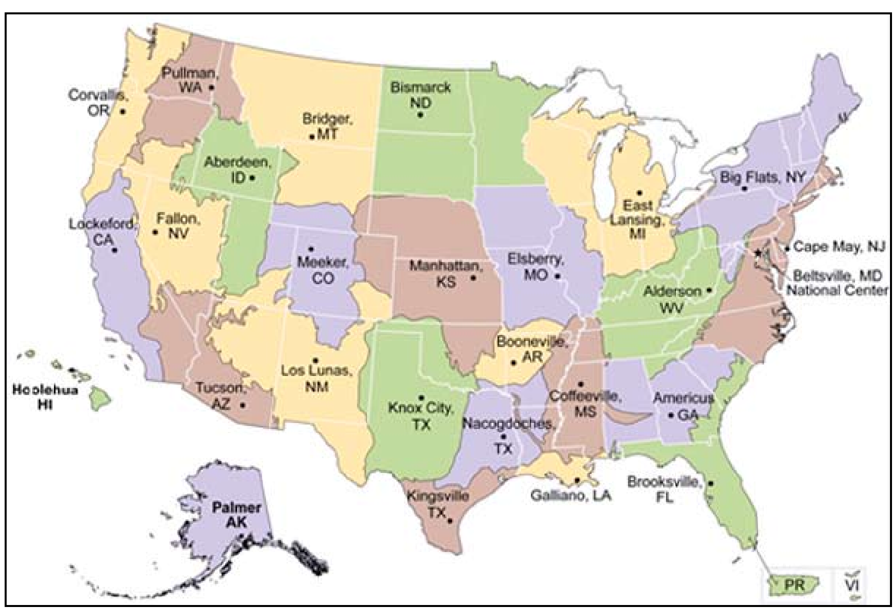
**Cover photo:** Harvesting dormant switchgrass for biofuel (Photo by Don Tyler, University of Tennessee)

# Preface

The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Plant Materials Program has been involved in the collection, evaluation, selection, increase, and release of conservation plants for 76 years. Switchgrass (*Panicum virgatum* L.) was quickly recognized as one of the key perennial grasses for soil conservation following the dust bowl era of the 1930s. The first named switchgrass cultivar, 'Blackwell', was released in 1944 by the NRCS Manhattan, Kansas, Plant Materials Center (PMC) in cooperation with the Kansas Agriculture Experiment Station. Since then, a total of 18 switchgrass cultivars and prevarietal selections have been released by the Plant Materials Program and its cooperators (State Agriculture Experiment Stations, USDA Agriculture Research Service (ARS), and other State and Federal agencies). It is from these monumental efforts undertaken by the NRCS and its conservation partners that the majority of the switchgrass cultivars mentioned in this publication ('Alamo', 'Kanlow', 'Cave-in-Rock', 'Carthage', and 'Forestburg') and current technology on the use of switchgrass as a biomass energy crop have been produced.

This publication was prepared to provide information needed by conservationists, producers, or consultants to establish and manage switchgrass as a biomass crop. For additional information on establishment and management of switchgrass, refer to the literature section or the other suggested reading materials at the back of this publication. For specific information on cultivar selection, cultural specifications, and soils and climate requirements, consult the NRCS Field Office Technical Guide (FOTG) at http://www.nrcs.usda.gov/technical/eFOTG/, or contact the nearest PMC or Plant Materials Specialist (http://plant-materials.nrcs.usda.gov/contact/) and/or the Land Grant Universities that serves the State. Also, see technical resources on the National Plant Materials Program Web site at http://www.plant-materials.nrcs.usda.gov/.

Location and service areas of Plant Materials Centers



# Acknowledgments

This technical note was written by:

**Joel Douglas**, plant materials specialist, U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), Central National Technology Support Center (CNTSC), Fort Worth, Texas

**Jerry Lemunyon**, agronomist, USDA NRCS, Central National Technology Support Center, Fort Worth, Texas

**Richard Wynia**, manager, USDA NRCS, Manhattan Plant Materials Center, Manhattan, Kansas

**Paul Salon**, plant materials specialist, USDA NRCS, Syracuse, New York

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# Planting and Managing Switchgrass as a Biomass Energy Crop

## Introduction

Switchgrass (*Panicum virgatum* L.) is a perennial, native, deep-rooted, warm-season grass that occurs naturally throughout the United States except for the states of Oregon, Washington, and California (U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS) (2006) (fig. 1)). It tolerates a wide range of soil and climatic conditions and is widely acclaimed as a conservation plant for erosion control, pasture and hayland forage, wildlife habitat, and native prairie restoration (Alderson and Sharp 1994). The U.S. Department of Energy has designated switchgrass as one of the principal biofuel species recommended for combustion, gasification, and liquid fuel production (McLaughlin et al. 1996). Some of the characteristics that make switchgrass an ideal renewable energy crop include commercial seed availability of high-yielding cultivars adapted to different geographical regions of adaptation, relative ease of planting and establishment, compatibility with conventional farming equipment for establishment and harvest management, production of large amounts of biomass under a wide range of environmental conditions, and excellent wildlife cover provided (Wright 2007) (fig. 2). Switchgrass also has great potential to protect the environment through carbon sequestration and erosion control (Liebig et al. 2008; Dewald et al. 1996).

## Establishing switchgrass

Establishing switchgrass can be a challenge to producers unfamiliar with the cultural aspects of planting a tallgrass prairie species. Like commodity crops grown for food and fiber, switchgrass has its own set of cultural requirements to plant and manage it as a biomass crop. There are several factors that a producer must consider during the planning stages of a switchgrass biomass production system. Cultural specifications and management considerations for this type of system are described in this technical note.

### Field selection

A primary goal of biomass production is to produce high yields with minimal inputs. When selecting fields for switchgrass biomass production, use soil and field criteria typically used for row crop agriculture. Avoid fields with perennial weed infestations, steep or irregular terrain, and excessively wet areas because of their

**Figure 1** Switchgrass area of occurrence

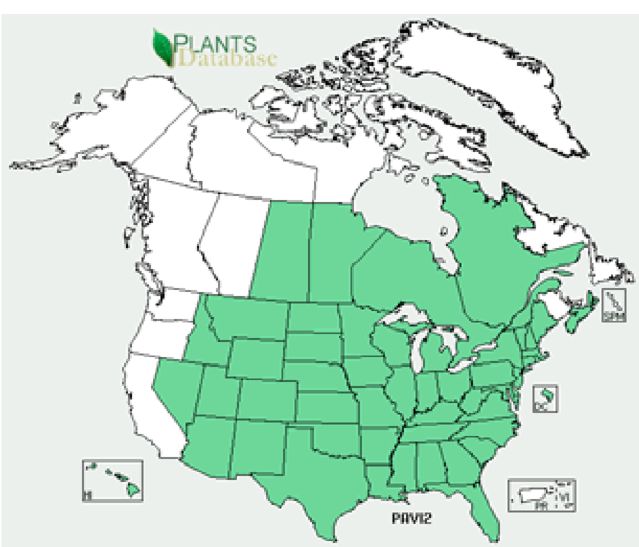



**Figure 2** Cave-in-Rock switchgrass is a high biomass producing cultivar released from the USDA NRCS Plant Materials Center, Elsberry, MO

*USDA NRCS Elsberry, MO*

negative effect on stand establishment and management and on field and harvest operations. Productivity is highest on medium- to high-fertility soils that are moderately fine textured, well- to moderately well drained, and have a pH of 5.5 to 6.5.

Switchgrass can be produced on a wide range of soil and landscape conditions. Although it is most productive on class I, II, and III lands, switchgrass can also grow on class IV and VI lands as long as the proper growing conditions and crop requirements exist. Highly productive class I and II lands will produce more biomass than class III and IV lands, and usually with more efficient production from inputs of water, nutrients, and energy. Landscapes that are suitable to seeding, application, and harvesting equipment are suitable for switchgrass production. Current marginal land for row crop production can be efficiently used for switchgrass production if the proper management and inputs are performed. Refer to section II in the local Field Office Technical Guide (FOTG) for specific information on suitable field characteristics for establishing switchgrass.

### Preparing the field

If the field selected for switchgrass biomass production was previously in a row crop, minimal, if any, tillage is needed to convert it from row crop production to switchgrass production. One of the biggest advantages of planting switchgrass in a previously cropped field can be low weed pressure (fig. 3). If the field has a history of poor weed control, remedial measures will be needed due to weed seed present in the soil seed bank. Herbicide application from previous cropping system must be considered to avoid potential carryover effects. Consult manufacturers herbicide labeling or contact the county extension agent for assistance with herbicide questions. If the field has not been cropped for several years, an additional year of site preparation may be required to control existing weeds. This can be done by chemically or mechanically fallowing the field, or growing a row crop such as glyphosate-tolerant soybeans (*Glycine max*) on the field. This system, unlike fallowing, gives the producer flexibility in controlling annual and perennial weeds, maintains a canopy cover for further weed suppression, improves soil quality, and provides the producer with an income from the field for another year.

**Figure 3** Switchgrass 6 weeks after planting in North Dakota

*USDA NRCS Bismarck, ND*

In northern States, it is important to avoid fields with somewhat poorly drained or variable soil drainage conditions because of the danger of frost heaving, which can be a serious threat to switchgrass stand establishment. Additionally, weed control and early planting are very important to allow sufficient root system and tiller development by the end of the first season to reduce susceptibility to frost heaving.

A soil test should be conducted the year before planting the field to correct any major nutrient deficiencies or soil pH problems. Procedures for taking soil samples and submitting them for analysis are available at the local county extension office. If no specific soil test response curve is available for switchgrass biomass production, treat it as an annual warm-season grass crop (sudex or sudangrass (*Sorghum* spp.)). Nutrient requirements for switchgrass are much lower than for annual row crops, which remove more nutrients with the harvested portion of the crop. Excessive fertilization may cause lodging, leading to harvesting difficulty and possible stand reduction, and may contribute to weed competition (Fike et al. 2006) (see fertilization).

### Seedbed preparation and seeding

Switchgrass seed is smaller than most row crop seed and should be planted no more than a quarter- to half-inch deep. Seed can be no-till planted into stale seedbeds if crop and/or weed residue has been controlled prior to planting. There are several advantages to no-till planting including conserving soil moisture and saving fuel, labor, and time. Another advantage of no-tilling switchgrass seed is less soil disturbance, which reduces soil erosion and may reduce weed population.

Switchgrass can also be planted into a conventionally prepared seedbed. It is critical that the seedbed seed is firm and free of competing vegetation. Correct seedbed firmness is when an adult footprint is only slightly visible on the prepared seedbed prior to the seeding operation (fig.4). Loose, uneven, fluffy, or cloddy seedbed can result in reduced stands or complete failure.

A prepared, tilled seedbed can be firmed, if needed, by pulling a culti-packer or homemade packer or roller over the field.

Regardless of the planting system used, surface crop or weed residue can affect seeding depth and seed-to-soil contact. The allowable amount of residue depends on the seeding equipment to be used. Tillage, fire, and mowing can be used to manage residue prior to seeding. Heavy accumulation of residue should be distributed over a larger area to make seed placement more accurate.

### Cultivar selection

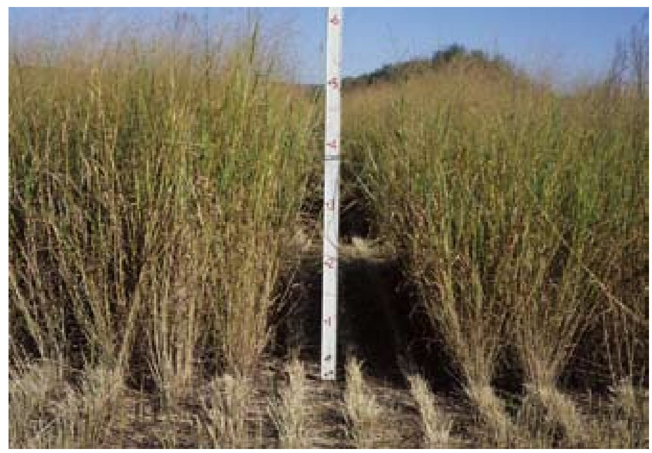
Commercially available switchgrass cultivars with high biomass production potential have been evaluated in field trials by the USDA Agricultural Research Service (ARS) and NRCS, universities, and private research institutes (Lemus et al. 2002; Cassida et al. 2005; Lee and Boe 2005; McLaughlin and Kszos 2005; Adler et al. 2006; USDA NRCS 2007, 2009) (fig. 5). These field trials have provided valuable data on cultivar performance, management, and persistence on various soils and under various climatic conditions in northern, mid, and southern latitudes. In general, these studies have shown that lowland cultivars, such as Alamo and Kanlow, are better adapted in the southern and mid latitudes, whereas the upland to intermediate cultivars, such as Cave-in-Rock, Sunburst, and Forestburg, are better adapted to mid and northern latitudes (McLaughlin and Kszos 2005) (fig. 6).

**Figure 4** Slightly visible adult footprint on a firm seedbed for planting switchgrass

*USDA NRCS Bismarck, ND*

In addition, other research has shown that upland populations cannot be moved south of their point of origin by more than one plant hardiness zone, and lowland populations should not be moved north of their point of origin by more than one hardiness zone without expecting severe losses in biomass yield and survival (Casler et al. 2004). Adaptation zones for some of the currently recommended biomass switchgrass cultivars are shown in table 1. These adaptation zones should only serve as a general guide to the areas where these cultivars can be planted, since selection and breeding

**Figure 5** Switchgrass biomass cultivars at the USDA NRCS Plant Materials Centers in Manhattan, KS



*USDA NRCS Manhattan, KS*

**Figure 6** Dacotah switchgrass (left) matures earlier than Sunburst (right). Sunburst is one of the recommended cultivar for biomass production in the northern Great Plains.

*USDA NRCS Bismarck, ND*

**Table 1** Switchgrass cultivar origin and adaptation expressed in United States plant hardiness zones[1/]

| Cultivar | State of origin | Plant hardiness zone | |
|---|---|---|---|
| | | Origin | Adaptation |
| Alamo | Texas | 8b | 7a, 7b, 8a, 8b |
| Kanlow | Oklahoma | 7a | 5a, 5b, 6a, 6b, 7a, 7b, 8a, 8b |
| Carthage | North Carolina | 7a | 6a, 6b, 7a, 7b, 8a, 8b |
| Cave-in-Rock | Illinois | 5b | 4b, 5a, 5b, 6a, 6b |
| Forestburg | South Dakota | 4b | 3b, 4a, 4b |
| Summer | Nebraska | 5a | 3b, 4a, 4b, 5a, 5b, 6a, |
| Sunburst | South Dakota | 4b | 3a, 3b, 4a, 4b |

1/ USDA Plant Hardiness Zone Map (http://www.usna.usda.gov/Hardzone/ushzmap.html)

can rapidly change the range of potential adaptation of switchgrass populations to latitudinal differences (Casler et al. 2004). In addition to those cultivars listed in table 1, there will soon be other suitable cultivars that have been developed specifically for bioenergy production by universities, the USDA ARS, and private research institutes. A recent example is BoMaster, which was released jointly by USDA ARS and North Carolina State University (Burns, Godshalk, and Timothy 2008). These are in the early stages of commercial increase and will be available for use by producers in the near future.

## Pests, insects, and diseases

There are some known pests and insects that negatively impact the production of switchgrass. Rust (*Puccinia* sp.) has been reported on switchgrass in South Dakota (Gustafson, Boe, and Jin 2003) and noted on switchgrass at the NRCS Jamie L. Whitten PMC near Coffeeville, Mississippi, and the East Texas PMC near Nacogdoches, Texas. A smut fungus (*Tilletia maclaganii*) that caused significant seed and biomass loss was identified on switchgrass at the USDA NRCS Big Flats, New York, PMC and reported on Cave-in-Rock switchgrass in southern Iowa (Gravert, Tiffany, and Munkvold 2000). This smut was also prevalent in the switchgrass cultivars Blackwell, Cave-in-Rock, Pathfinder, Shelter, Summer, and accession 9006010 at the NRCS Manhattan, Kansas, PMC, but did not occur in the cultivar Kanlow at this site (Stuteville, Wynia, and Row 2001).

A switchgrass moth (*Blastobasis repartella*) was reported on young tillers of switchgrass that could potentially impact stand and production in the northern Great Plains (http://nathist.sdstate.edu/BioEnergy/blastobasis.html). The likelihood of additional pests and insects that affect switchgrass production may increase as more acres are planted for biomass production.

## Seed quality and planting rate/date

Switchgrass biofuel stands are expected to have a production life span of more than 10 years (Fike et al. 2006; Parrish and Fike 2005). Planting the best available seeds goes a long way to ensure successful stand establishment and maximum longevity. To ensure the best quality seed is used, plant only certified seed. Certified seed guarantees the best quality seed, true to the cultivar stated on the seed tag that has met rigorous germination and purity analysis and weed seed standards. Using noncertified seed may result in poor stands or a field of weeds that compete with the switchgrass for nutrients, light, and moisture.

Switchgrass seed is purchased and planted on a Pure Live Seed (PLS) basis because germination rates can be poor and dormancy rates can be great. This can occur even when produced under the best growing conditions. A planting rate expressed as pounds PLS per acre is not the same as a planting rate in pounds bulk seed per acre.

To calculate the amount of switchgrass seed to plant in pounds per acre, divide the recommended PLS planting rate by the calculated percent PLS of your purchased seed (expressed as a decimal value) (fig. 7). More information on determining percent PLS can be found in the Aberdeen, Idaho, PMC publication

**Figure 7** Calculating PLS

$$\%\ \text{PLS} = (\%\ \text{purity} \times \%\ \text{viability}) \times 100$$

$$\%\ \text{viability} = \%\ \text{germination} + \%\ \text{dormant seed}$$

*USDA NRCS Bismarck, ND*

Reading Seed Packaging Labels and Calculating Seed Mixtures (http://plant-materials.nrcs.usda.gov/pubs/idpmstn04265.pdf).

It is important to be aware that there can be wide variation among switchgrass seed lots between germinating seed and dormant seed even though the percent PLS is the same. In most cases, a seed lot that has a high percent purity and germination rate with little dormant seed will be the most advantageous to purchase.

It would also be beneficial to know whether seed germination was determined with or without stratification. A standard stratification treatment is to prechill the seed for 2 weeks using a cold, moist stratification period (AOSCA 1993). This short prechill period helps break the dormancy of some of the seed resulting in a higher germination percentage than when not given a prechill treatment. Switchgrass seeds can be prechilled and properly stored until planting. Some seed growers offer stratified (prechill) switchgrass seed as an alternative to nonstratified seed. However, stratified seed must be planted into a warm, moist seedbed to achieve maximum germination. If stratified seeds are planted in a dry seedbed or the seedbed dries out before germination, the seed becomes susceptible to a secondary dormancy and may not germinate until the next spring (Shen et al. 2001).

An alternative method that has been used in colder regions of the United States for breaking seed dormancy in switchgrass is no-till planting the seed in late November or December. The seed over winter in the soil and the cool, moist soil conditions will result in a natural stratification process that will help break dormancy. However, stand consistency of late fall and early winter plantings vary from year to year. If nonstratified seed is going to be used, seeding rates may need to be increased if the seed lot contains a high percentage of dormant seed. One easy way to ensure that seed dormancy is not excessive is to purchase seed that is at least one year old because percent seed dormancy reduces as the seed ages.

Seeding rates and planting dates can vary widely across the area of adaptation for switchgrass cultivars (table 2). Factors that influence seeding rates and planting dates include, but are not limited to the region of the United States, soil moisture and temperature, row spacing, and number of seed per pound. Consult the local FOTG or local extension service for seeding rates and planting dates for switchgrass cultivars recommended for the State and county.

Switchgrass seed should be planted at a depth between a quarter to half inch when soil moisture and temperature are at levels acceptable for germination. In general, soil moisture conditions for planting are ideal when the soil can be readily formed into a ball in the palm of the hand and break easily when dropped. The optimum planting depth depends on soil texture. In general, switchgrass seed is planted a half-inch deep in coarse-textured soil and a quarter-inch deep in fine-textured soil. The purpose of a deeper planting depth on coarse-textured soils is to provide higher soil moisture levels for germination. A minimum soil temperature of 60 degrees Fahrenheit is needed for switchgrass seed to germinate. Germination and seedling growth will be slow at this temperature, but will increase at higher temperatures.

Because of a narrower planting window in the northern areas of its range, it may be necessary to plant switchgrass seed in the spring before soil temperatures reaches 60 degrees Fahrenheit. Planting seed this early has some advantages. First, the seed is exposed to a natural, light stratification, which may increase its germination rate. Second, adequate soil moisture for germination is usually present. Third, there will be a longer growing season to allow for better root development.

**Table 2** Examples of the variation in recommended seeding rates and planting dates of switchgrass cultivars in different regions of the United States 1/

| Region | Cultivars | Planting rate (lb PLS/acre) | Approximate planting dates |
|---|---|---|---|
| Northern Great Plains | Summer, Sunburst, Forestburg | 3.5–5.0 | Mid-May to late June |
| Midwest | Kanlow, Cave-in-Rock | 5.0–6.5 | Late April to mid-June |
| Southern Plains | Alamo, Kanlow | 3.0 | Mid-April to mid-May |
| Southeast | Alamo | 6–8 | Late March to mid-June |
| Northeast | Cave-in-Rock, Kanlow, Carthage, Sunburst | 8 | Late April to mid-June |

1/ Refer to the eFOTG for specific seeding rates and planting dates for specific areas.

## Planting equipment

Switchgrass seed are small and requires planting equipment that can properly place the seed at a uniform, shallow depth and in a uniform distribution pattern that will allow for good seed-to-soil contact. Culti-packing before and after planting is an option. Grass or small grain drills can place the seed properly as long as they can maintain a shallow and consistent planting depth and are equipped with press wheels to firm the soil around the seed (fig. 8). Drills equipped with depth bands on double disk openers that ensure a consistent, proper planting depth for the seed are particularly good for switchgrass planting. Practical experience has shown that if a few seed are not present on the soil surface regardless of the planter type, suspect that the seed are being planted too deep (USDA NRCS 2003).

Row planting is preferred over broadcast planting. Research in the southern plains has shown there to be only a minimal increase in biomass yield when row spacing of 7, 14, and 21 inches were used (Muir et al. 2001). In this case, either spacing would be acceptable unless additional research supports another recommendation. In the upper South and Northeast, a 7-inch row spacing is recommended because it provides early canopy closure that helps reduce weed competition. In the Deep South, a 21-inch row planting, in contrast to 7- to 10-inch spacing, was shown to be advantageous for early canopy closure for weed control and maintenance of switchgrass (harvesting, side dressing, and row cultivation, if necessary). In this case, the wider row spacing permitted equipment to travel between rows, resulting in less plant damage from tire traffic and improving the ease of harvest operations. This row spacing width may also accommodate the interplanting of winter annual and perennial legumes between rows. These interseeded legumes can provide partial nitrogen requirements of the switchgrass crop (fig. 9). Interseeding with cool season perennial legumes is not recommended in the Northeast because they become too competitive with the switchgrass plants.

**Figure 8** Drill equipped with depth bands and packer wheels

*USDA NRCS Bismarck, ND*

**Figure 9** Ball clover interseeded into Alamo switchgrass at the USDA NRCS East Texas Plant Materials Center near Nacogdoches, TX, (early spring growth of Alamo and ball clover (top)/late spring growth of Alamo and ball clover (bottom)

*USDA NRCS Nacogdoches, TX*

## Stand evaluation

Stand success is generally evaluated by determining seedling density and distribution of seedlings across the field. This assessment should occur within 6 to 10 weeks after spring planting. A simple, fast, and reliable method for evaluating stand establishment is using a frequency grid (Vogel and Masters 2001). The frequency grid is 2.5 by 2.5 square feet that contains 25, 6- by 6-inch open cells. The grid is placed on the soil surface and the number of seedlings in each cell is counted, and then the grid is flipped three times, end-over-end, until a total of 100 cells is observed (fig. 10). A running total of the number of cells containing one or more seedlings is made. To determine percent stand, divide the total number of cells containing a seedling by 100. The grid should be used to take measurements at several representative locations across the field. If 40 percent or more of the grids contains seedlings, it is considered an acceptable stand of switchgrass for bioenergy production (Schmer et al. 2005). Another method for determining seedling density is counting the number of seedlings in a 1-square foot quadrant at several representative locations in the field. Three to six plants per square foot is considered an acceptable switchgrass stand at 6 to 10 weeks after planting. One to two plants per square foot is considered an adequate stand for biomass production at the end of the second year (fig. 11).

## Weed control

Slow germination of switchgrass, slower seedling shoot growth compared to annual weeds, and relatively low tolerance for shade makes weed control at planting and during the establishment year important. There are herbicides labeled for pre- and postemergence control of weeds in switchgrass; however, it is important to consult with extension weed specialists or the county extension agent to determine which ones are registered for use in the State and county. Any information regarding herbicide application is based on current availability and labeling. If herbicides are to be used for weed control in a switchgrass biomass production system, follow current Land Grant University recommendations; and adhere to label instructions.

A nonselective, broad spectrum herbicide can be applied prior to planting or before switchgrass emergence. Weeds can also be controlled mechanically with a rotary mower. The goal is to reduce the weed canopy so the switchgrass seedlings can grow and to prevent weeds from producing a seed crop. Adjust the rotary mower to a height at or above the top of the switchgrass seedlings to prevent cutting or severely damaging the growing points on the seedlings. Mowing should be performed as often as necessary to control weeds during the first year.

Traditional row crop agriculture is generally depicted as uniform fields of a single crop such as corn (*Zea mays*) growing on level to gentle rolling fields that are weed free. However, switchgrass grown for biomass may not necessarily portray this type of agriculture. Weeds can be common the first few years in switchgrass fields. Do not assume that the planting is a failure if weeds are present in the field and the switchgrass plant population appears sparse. As the switchgrass plants produce tillers and plants increase

**Figure 10** Frequency grid used to assess stand success of switchgrass

*USDA NRCS Manhattan, KS*

**Figure 11** Switchgrass reaches full production 3 years after planting

*USDA NRCS Booneville, AR*

in size over time, they will begin to shade other plants around them and become more competitive than most of the annual and perennial weeds. Furthermore, in the southern United States, switchgrass plants recover from winter dormancy period better than most introduced warm-season grasses and broadleaf weeds. This means that switchgrass is more competitive than many warm-season weed species early in the growing season. Also, annual weed pressure is usually less the second year, and in subsequent years, due to lack of further soil disturbance.

## Possible reasons for poor stand establishment

Several factors can cause stand failures in switchgrass including, but not limited to, cultural practices, environmental stresses, and seedling damage. Some of the more common causes are listed below:

- poorly prepared seedbed—seedbed too loose for good seed-to-soil contact
- seed planted too deeply—seed germinate but seedlings fail to fully emerge
- high seed dormancy—seed did not germinate uniformly in the rows
- excessive weed pressure—competition with seedlings for moisture and light
- lack of rainfall after planting—seedlings emerge but die due to prolonged drought conditions
- frost heaving—seedlings are pushed out of the soil by frost action, exposing the roots to drying
- herbicide damage—injury to young seedlings results in low stand percentage or seedling death
- mowing the seedlings too closely in the establishment year—clipping below the growing point of the young seedlings
- damage by wildlife—slow growth due to reduced leaf area or seedlings killed by grazing too closely

## Fertilization needs the first and subsequent years

### Nitrogen—establishment year

Because switchgrass is slow to establish, applying nitrogen fertilizer the first year or until a stand of grass is deemed adequate is discouraged (see Stand evaluation). Applying nitrogen fertilizer to a newly planted field of switchgrass will only encourage weed competition, which hinders switchgrass seedling growth and development.

### Nitrogen—production years

Nitrogen management for switchgrass biomass production differs markedly from switchgrass managed as livestock forage. For forage production, nitrogen application rates and timing are directed toward producing high nutritional quality forage, whereas nitrogen rates for switchgrass grown for bioenergy seek to maximize biomass production. Nitrogen concentrations in switchgrass forage (harvested at the boot stage) ranged from 1.6 to 2.2 percent (Ball, Hoveland, and Lacefield 2002), while nitrogen concentrations for a switchgrass biomass crop ranged from 0.3 to 0.6 percent when harvested as a single crop in late fall (Lemus, Parrish, and Wolfe 2009). Less nitrogen has shown to be removed in the biomass in the late-fall harvest compared to a two-cut harvest (midsummer and late fall) because of translocation of nitrogen and other nutrients in late fall to the plant crown and root systems. This indicates that less nitrogen may be required for switchgrass production when the biomass is harvested in late fall (Fike et al. 2006; Lemus, Parrish, and Abaye 2008).

Studies have shown that switchgrass biomass production is not consistent with different levels of nitrogen fertilization. Differences between studies with regards to cultivars, cutting management, and soil type on which the research was conducted plus climate and precipitation extremes at northern and southern latitudes are some of the factors that contributed to the variation in yield response to nitrogen (Muir et al. 2001; Vogel et al. 2002; McLaughlin and Kszos 2005). For this reason, blanket recommendations on nitrogen fertilization cannot be made without considering the soil and site characteristics.

Sustainable switchgrass production will depend on long-term adjustments to soil fertility. In addition to periodic soil sampling and analyses to monitor soil nutrients, there are some intrinsic physical characteristics that can help guide annual soil fertility management. Soils that provide for deeper rooting depth will allow the switchgrass plant to explore a greater soil volume and utilize nutrients from deep in the profile. Rooting depths greater than 20 inches are considered ample for supplying moisture and nutrients for root growth and plant vigor. Likewise, loam, silty, and clayey soil textures retain soil nutrients and moisture better than coarse-textured soils. Soil with high organic matter levels (>2.5%) can mineralize nitrogen that is then available to the crop. When switchgrass is grown on these more productive soils, apply 50 to 100 pounds per acre per year nitrogen during the second year

(year after establishment) of production to accelerate tillering and plant growth, followed by 50 pounds per acre per year in subsequent production years (Garland 2008; Lemus, Parrish, and Wolfe 2009). Soils with a shallow, eroded topsoil, a coarse profile texture in the root zone, and low soil organic matter have minimum nitrogen supplying power and will need annual nitrogen applications greater than 100 pounds per acre per year. Nitrogen fertilizer needs to be applied when the plant begins active growth or when regrowth reaches 6 to 8 inches. Split applications are more suitable for rates greater than 100 pounds per acre or for a two-cut harvest system.

**Lime, phosphorus and potassium**

*Establishment year*—Prior to planting, adjust P and K levels in the soil to a medium level according to soil test analysis and crop recommendation using a warm-season grass, such as sudangrass, as a soil test guide. If soil pH is less than 5.0, apply sufficient lime to raise pH to 6.0 to 6.5 to allow for more efficient utilization of soil nutrients.

*Production*—A single harvest in late fall has produced switchgrass yields in excess of 9 to 10 tons per acre in the southern United States, 4 to 5 tons per acre in the Northeastern and Midwestern United States, and more than 6 tons per acre in the Mid-Atlantic States (McLaughlin and Kszos 2005). Removal of P and K from the soil in the harvested biomass must be considered to maintain long-term sustainable switchgrass yields. Removal rates of P and K vary considerably and are dependent on growing season, yield, timing of harvest, precipitation, and soil quality. One ton of switchgrass may remove approximately 4 pounds per acre P and 40 pounds per acre K (Fixen 2007). These nutrients will need to be replaced through proper fertilization following soil test recommendations. A soil test should be taken every 3 years to maintain P and K at a medium soil test level. Once soil test levels of P and/or K drop into the low category, annual soil test monitoring plus fertilizer applications are recommended. Like nitrogen fertilizer, P and K can be broadcast applied in the spring when the plants begin active growth or when regrowth reaches 6 to 8 inches.

## Soil conditions at harvest

As with any crop production system, field and crop conditions at harvest will depend on the weather. Heavy rains and wet soils during harvest will provide poor drying conditions for the harvestable biomass. Biomass spoilage and formation of molds during storage are possible. Wet soils at harvest can reduce field access and cause rutting, and damage to plant crowns. Dry or frozen field conditions will provide support to harvest equipment without damaging the switchgrass plants or soil surface. In parts of the North and Northeast, snow accumulation can effect late fall harvesting.

## Harvest management

Weather, soil conditions, farm workload, and the quality of the feedstock to satisfy the various biofuel conversion systems of direct combustion, ethanol production, and thermochemical conversion processes (Lewandowski and Kicherer 1997; Boateng, Hicks, and Vogel 2006) may dictate frequency of harvest for optimizing biomass production. Harvesting the switchgrass once a year appears to be the most economical harvest system for biomass production. The timing of the harvest should be approximately 1 month after the first killing frost (McLaughlin and Kszos 2005; Parrish and Fike 2005). However, it may take several killing frosts before the plant is totally dormant. In addition, delaying harvest until several weeks after frost allows for translocation of nutrients in the biomass back to the stem bases and root system. It also improves feedstock quality due to low moisture content in the aboveground biomass, as well as a reduction in nitrogen content, other minerals, (K, Ca), and ash concentrations that can cause direct combustion systems to fail (Miles et al. 1996; Lewandowski and Kicherer 1997). This strategy conserves nutrients in the soil while reducing the amount of nutrients removed in the harvestable biomass. However, delaying harvest for an extended period after frost may result in significant biomass loss. This is due to winter weather conditions which causes loss of dry matter (leafy tissue), degradation of the biomass, and complicates harvesting operations and ultimately harvests efficiency (Adler et al. 2006) (fig. 12).

**Figure 12** Delaying harvest of switchgrass until after frost improves feedstock quality.

*Don Tyler, University of Tennessee*

Factors such as weather and field conditions in the fall in different regions of the United States may complicate harvesting and baling of the switchgrass (Cherney 2005). A two-cut system may be the only reliable option for harvesting switchgrass biomass on some soils in the wetter, cooler regions of the United States. Generally in a two-cut system, the switchgrass is harvested in mid- to late summer and the second harvest is made in the fall, as weather permits. One problem is that the nitrogen concentration in the biomass is relatively high for the first harvest. An option for handling switchgrass biomass from a summer harvest is to leave it windrowed in the field until the nutrients and ash concentrations meet the desired levels for a specific conversion process (Cherney 2005). The costs of a second harvest must be also considered when making this management decision (Vogel et al. 2002). Another consideration with a two-cut system is the quality of the feedstock and fertilizer management. Because of the potentially high removal of nitrogen in the harvestable biomass, additional nitrogen fertilizer may need to be applied following the first harvest in a two-cut system.

Regardless of harvest system, switchgrass should be mowed no lower than a 6-inch stubble height to reduce tire damage (Garland 2008), trap snow/retain moisture, reduce soil erosion, and provide some cover for wildlife. Cutting the switchgrass lower than 6 inches will produce stiff, hard stems that may puncture tires on tractors or harvesting equipment. A 6-inch cutting height will also allow switchgrass to maintain nutrients and carbohydrates in the stem bases that are necessary for spring regrowth and result in improved plant stands (fig 13).

**Figure 13** A 6-inch stubble height may reduce tire damage on harvesting equipment.

*USDA NRCS Manhattan, KS*

A traditional, sidebar-type sickle mower can be used to cut switchgrass the first and possibility the second year harvest after establishment. However, in subsequent years as the switchgrass plants reach full maturity, that type of mower will not be able to cut the switchgrass, especially when making a single harvest in late fall due to the large diameter of the stems and the inability of the sickle to maintain a consistent cutting height of 6 inches. A disc-type mower becomes more effective, but may also present a challenge as the height of the switchgrass may reach 6 to 8 feet by late July in the Southeast and by the fall in many regions of the United States. Mowers equipped with swinging flail blades may have more merit than a disc-type mower for cutting mature switchgrass. Crushing or conditioning the biomass prior to baling is not recommended.

Moisture content is an important consideration in baling switchgrass biomass. High moisture content of the biomass affects feedstock quality and excess moisture increases transportation costs. Switchgrass is typically baled at moisture contents of 13 to 15 percent (McLaughlin et al. 1996). Large round (5 ft by 4 ft) or square (4 ft by 4 ft by 8 ft) bales have been shown to be acceptable methods for transporting and storing switchgrass. Square bales are reported to be easier to handle, store, and transport (Garland 2008). Another potential alternative is to use or modify a silage chopper to harvest the switchgrass as a loose, noncompacted material.

As the biomass industry continues to evolve, development of new equipment and/or modifications of existing equipment will provide the producer with better technology and methods to meet future challenges of harvesting and transporting biomass from the field to the biorefinery.

## Wildlife considerations

Landscape changes in the Great Plains are associated with change in the communities of birds and other animals that rely on grassland habitats. For example, dramatic declines in grassland bird species since the 1950s are attributed to changes in the agricultural landscape of the region (Gerard 1995). Cultivation and management of switchgrass for biomass production has the potential to provide substantial benefits for grassland associated wildlife. Wildlife use of switchgrass fields during spring and summer is probably most critical. Field selection, establishment, maintenance, and harvest should be given special consideration if managing for wildlife is one of the objectives of the landowner (tables 3–5, W. Hohman, personal communication). Field selection should include fields

**Table 3** Field selection for switchgrass biomass production

| **Field selection** | **Production** [1/] | **Wildlife** |
|---|---|---|
| Field size and width | Varies depending on the farm size and land use | 10–20 acres or > 60 ft |
| Field location/configuration | Clustered blocks of land | Clustered blocks of land |
| Adjacent land-use | Varies with crop and rotation system | Perennial herbaceous or annual cropland |

1/ Characteristics largely influenced by land ownership and existing land use, but production efficiency would favor clustering of large block in close proximity to the biorefinery.

**Table 4** Establishment considerations for switchgrass biomass fields

| **Establishment** | **Production** | **Wildlife** |
|---|---|---|
| Seedbed preparation | Varies | Minimal tillage |
| Planting method | Varies | No-till |
| Seed mixtures | Monoculture [1/] | Multiple species |
| Seeding rate | Recommended rate | 25–30% reduction in recommended seeding rate |
| Weed control | Pre- or post-emergent | Pre-emergent |

1/ Production efficiency for diverse native plant stands may be competitive with monocultures (Tilman, Hill, and Lehman 2006)

**Table 5** Maintenance and harvest considerations for switchgrass biomass production

| **Maintenance** | **Production** | **Wildlife** |
|---|---|---|
| Fertilizer applications | As needed | Avoid during the nesting season |
| Pesticide applications | As needed | Consider spot treatment |
| Season of harvest | Dormant | Dormant |
| Frequency of harvest | Annual [1/] | Annual [1/]/rotational harvest [2/] |
| Harvest considerations | Moisture <15% | Daytime only |
| Height of harvested biomass | 4 to 6 inches | 8 to 10 inches |
| Pattern | Continuous | Minimize edge |

1/ Assumes a one-cut harvest system in late fall or early winter
2/ If field is less than 40 acres, harvest the entire field every other year. If field is greater than 40 acres, harvest one half per year or retain a minimum of a 20-acre unharvested block (not strip).

in close proximity to other switchgrass fields or near pastureland, hayland, and small grain crops. Reduce hard edges by removing mature trees from fence row. Between switchgrass fields and mature forest, establish a feathered edge comprised of herbaceous plants, shrubs, or small trees. Minimize production activities such as fertilizing and weed control during the nesting season until the young are mobile and have become independent. Furthermore, consider time of harvest in relation to wildlife usage. For example, if a dense, over-winter cover is needed for pheasants, then consider partial harvests, and retain an unharvested block adjacent to cropland.

Harvesting switchgrass after a killing frost will avoid harmful effects on wildlife, such as grassland nesting songbirds that use fields in spring and summer. Harper and Keyser (2008) suggest that postponing harvest until late winter would provide greater benefits for wildlife over winter. Delaying harvest may result in yield loss, but a higher biofuel quality may occur as a result of additional weathering of the biomass (Adler et al. 2005). Field borders and hedge rows established between fields and rights-of-way, with a diverse plant community that includes forbs, flowering trees, and shrubs is beneficial and highly recommended for pollinators (fig. 14). To obtain more information on managing wildlife in switchgrass biomass production, contact the local NRCS wildlife biologist.

## Stand longevity

If the best adapted cultivar is planted on a moderately fertile soil, soil nutrient levels are maintained through proper soil fertility management and harvest management, it is believed that a switchgrass bioenergy production field could potentially remain productive well beyond 10 years (Parrish and Fike 2005; Fike et al. 2006). Regardless of stand age, if there is a steady decline in switchgrass production over consecutive growing seasons and/or yields drop 30 percent from the normal production levels under proper management and growing conditions, it may be necessary to reestablish the switchgrass stand. An evaluation of the switchgrass cultivar, soil conditions (drainage, fertility, pH), and management techniques should be conducted to determine the cause of stand decline before proceeding with reestablishment (fig. 15).

**Figure 14** Field borders established between switchgrass fields and/or row crops can provide food and cover for wildlife and pollinators

*USDA NRCS Elsberry, MO*

**Figure 15** Switchgrass stands should remain productive beyond 10 years with proper management.

*USDA NRCS*

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