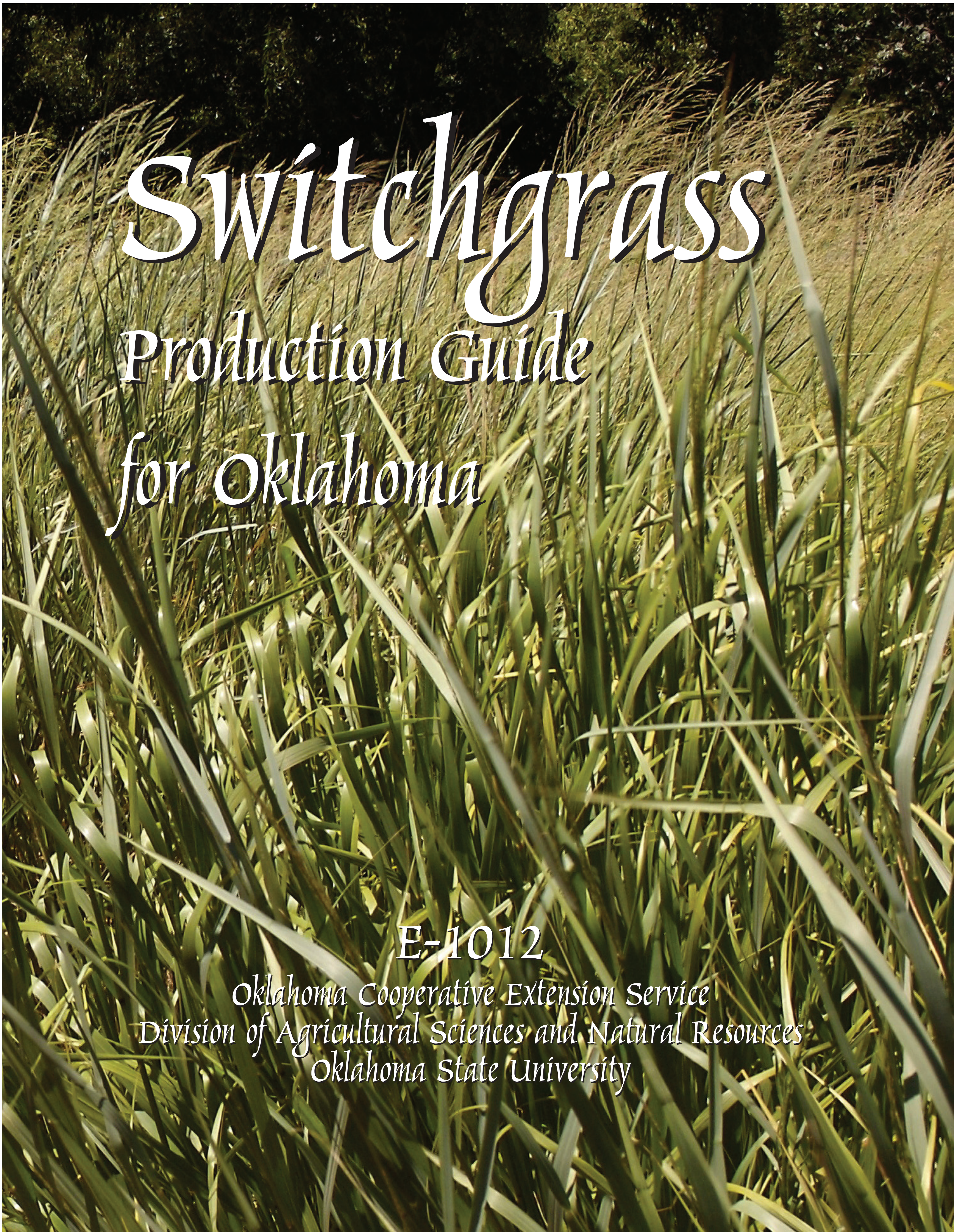


Switchgrass

Production Guide for Oklahoma

E-1012

Oklahoma Cooperative Extension Service
Division of Agricultural Sciences and Natural Resources
Oklahoma State University

Authors:

John Caddel
Professor Emeritus
Plant and Soil Sciences
Oklahoma State University

Gopal Kakani
Assistant Professor
Plant and Soil Sciences
Oklahoma State University

David Porter
Professor and Department Head
Plant and Soil Sciences
Oklahoma State University

Daren Redfearn
Associate Professor
Plant and Soil Sciences
Oklahoma State University

Nathan Walker
Associate Professor
Entomology and Plant Pathology
Oklahoma State University

Jason Warren
Assistant Professor
Plant and Soil Sciences
Oklahoma State University

Yanqi Wu
Assistant Professor
Plant and Soil Sciences
Oklahoma State University

Hailin Zhang
Professor
Plant and Soil Sciences
Oklahoma State University

Editors:

Janelle Malone
Extension Assistant
Plant and Soil Sciences
Oklahoma State University

Gayle Hiner
Graphic Design and Production Editor
Agricultural Communications Services
Oklahoma State University

Photography:

Cover photos:

Todd Johnson
Agricultural Communications Services
Oklahoma State University

Internal photos:

By OSU Personnel unless otherwise noted

Foreword: Potential for Oklahoma and the Southern Great Plains

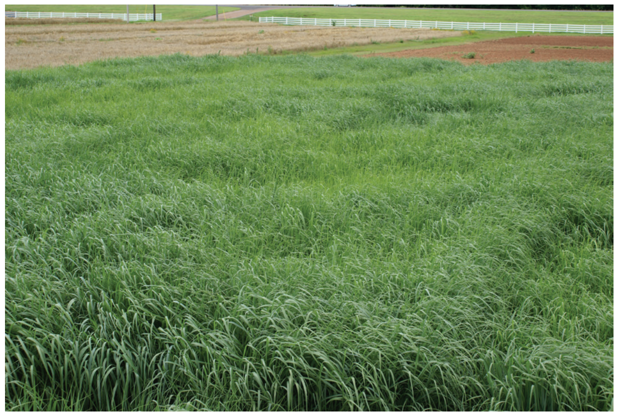
Switchgrass (*Panicum virgatum* L.) is a proven performer over the widely variable production settings of Oklahoma. As a native perennial grass, it has long been recognized as an important component of the productive tallgrass prairie plant community that dominated much of the Great Plains over the millennium. Given its history, the potential for it to persist under the sometimes harsh Oklahoma climate is without question.

With the advent of agriculture in Oklahoma, switchgrass was harnessed for a variety of uses to capture benefits derived from its growth habit and its ability to produce large quantities of biomass under conditions considered less than optimal for other crops. Switchgrass is often used for soil conservation and amendment largely because its massive fibrous root system adds to the organic material, permeability, and productivity of the soil. Its potential to minimize the wind and water erosion of soil also makes switchgrass a recommended planting for roadsides, strip mine sites, pond dams, and vegetated waterways.

Switchgrass has also been tapped as forage for beef cattle. It can be grazed or fed as hay to cattle, but its potential as forage for other animals may be limited by saponins, which are chemical compounds produced by switchgrass that can cause health problems in non-ruminant animals.

As outlined above, the potential of switchgrass to contribute to Oklahoma agriculture has been realized in a variety of forms and functions. However, it is the potential of switchgrass to contribute to the emerging biofuels industry that has received the most attention and has become the topic of some debate and speculation.

New techniques and technologies capable of converting cellulose to transportation grade ethanol fuel are under development here in Oklahoma and around the world. While these various conversion technologies may differ in principle and practice, they all utilize cellulose as a feedstock for the process. And, as a source of cellulose, switchgrass is considered the model plant system for a biofuels feedstock. The same qualities outlined above that make switchgrass ideally suited for sustained production of large quantities of biomass, make it the ideal candidate for supplying large quantities of cellulose to cellulosic ethanol plants.



Recent large, on-farm studies have shown that switchgrass grown for biofuels production can produce 540 percent more energy than is needed to grow, harvest and process it for cellulosic ethanol. Put another way, one unit of energy input produced 5.40 units of energy output. Given that kind of ratio, the energy potential for switchgrass as a biofuels feedstock is tremendous.

Once this new industry becomes established, large scale switchgrass production areas will need to be organized to support newly built cellulosic ethanol plants. Based on a conservative conversion rate of 75 gallons of ethanol produced from one ton of biomass, a 75 million gallon-per-year ethanol plant would need 1 million tons of biomass feedstock produced each year. Using a very conservative lowland ecotype switchgrass yield estimate of

5 tons/acre produced per year, it would require 200,000 acres of switchgrass to produce 1 million tons of biomass feedstock.

The potential of establishing 200,000 acres of switchgrass to provide feedstock to a 75 million gallon-per-year ethanol plant is certainly feasible, but will be driven by the economics of production and the pricing structure of feedstock sales to the cellulosic ethanol plant. Transportation, storage, and processing of harvested switchgrass are all variables that must be considered in the equation for economic feasibility of this particular model of a large volume cellulosic ethanol plant. Industry estimates of transportation costs for moving switchgrass from field to plant indicate production areas should be within a 50-mile radius of the ethanol plant. Two hundred thousand acres of switchgrass production would represent one out of every 25 acres in this 50-mile radius. Given that relatively small allocation of arable land needed for switchgrass production to support a large volume ethanol plant, it would seem reasonable that Oklahoma could support multiple cellulosic ethanol plants, particularly in the central to eastern parts of the state, where precipitation is more abundant for crop growth.

Switchgrass is the ideal plant system for producing large amounts of biomass to support a cellulosic ethanol industry in Oklahoma. There is great potential for the ethanol industry in Oklahoma, and switchgrass as a resource can fulfill it. However, other factors (i.e., economic, political, social, environmental, etc.) must be addressed and resolved before we can realize the full potential of switchgrass in Oklahoma.

David Porter

Switchgrass Production Guide for Oklahoma

1 What is Switchgrass? An Overview

Switchgrass (*Panicum virgatum* L.) is one of many warm-season perennial grasses native to North America. It is a natural component of the tallgrass prairie, which covered most of the Great Plains. It is also found on prairie soils from the southeastern U.S., westward to the Rocky Mountains, as far south as Mexico, and northward into Canada. After extensive evaluations of many plant species in multiple locations, switchgrass was selected in 1991 by the U.S. Department of Energy as a model herbaceous energy crop for the development of a renewable feedstock source to produce transportation fuel. While switchgrass has been promoted as a "savior" or the "answer to expensive, imported fuel," much work remains. The work will require many years of research and development.

Native grass

The fact that switchgrass is native to North America means:

- It is tolerant of many native insects and diseases;
- It can persist with little fertilizer, compared to most row crops;
- The need for agricultural chemicals to grow switchgrass is relatively low;
- It is unlikely to invade areas where it is not wanted; and
- It is tolerant of poor soils, extreme temperatures, flooding, and drought.

If switchgrass becomes widely produced in monocultures, disease, and insect problems may develop that are not serious problems in its natural habitat. Likewise, fertility needs also may change.

History

Most of the history of switchgrass was not recorded and cannot be written. This is because it was present in North America prior to the settlement by Europeans. As a natural component of the tallgrass prairie, which covered most of the Great Plains and some parts the southeastern U.S., it has always been here. Switchgrass is widespread across the state of Oklahoma.

Early switchgrass studies were designed primarily to understand how it could be used in natural mixes with other native species as a source of forage for grazing animals. Some of these studies examined the forage quality and yield when the forage was grazed at various times of the year. Other research looked into persistence of the grasses in response to grazing, burning, or haying. Later studies addressed questions about its role as habitat for wildlife.

As some of the early switchgrass studies were occurring, researchers realized the need for improved plants through breeding. This effort began as they collected seed from plants in an area, seeds from a few plants, or even a single plant. These seeds were often planted and multiplied, so the seeds from those collected plants formed unique ecotypes and sometimes were used as varieties; thus, the beginnings of the first "new" switchgrass varieties. It is important to note these "varieties" are not like those of wheat, corn, or many other crop species that have been cultivated for thousands of years. Wheat and corn plants in current varieties do not resemble those progenitors that served as the beginning for those crops. Man selected certain traits in these species and changed them drastically. The first selections were simply seeds the first people kept to grow when they changed from hunter/gatherers to primitive farmers. More recently, beginning in the middle part of the 20th century, plant breeders used much more sophisticated methods of selection and have hastened the rate of change in many cultivated crops.

Switchgrass varieties today are only a generation (or a few generations) away from its wild ancestors. Small, important changes have been made in some varieties, but overall switchgrass is still very wild. It could be said that switchgrass, as we know it today, is still a wild ancestor of something yet to be identified.

Many of our important cultivated crops have been selected under certain conditions common to farms around the world, and the plants will not grow well outside these environments. Switchgrass, on the other hand, is more at home on a roadside, on a grassy hillside range site, or in a productive permanent pasture along a creek, than in a cultivated field. In spite of its origin in native conditions, switchgrass does not always have high yields under stress conditions; frequently yields are economically low. As a native species, one can assume it will not become an invasive weed species.

Photo courtesy Les Crall, Producer and Southwestern Oklahoma State University.

Figure 1-1. Switchgrass seed is harvested.

Types of Switchgrass

Switchgrass evolved in many different environments – cold northern and warm southern areas; upland sites with shallow soils and in creek and river bottoms with deep soils – and as a consequence has many ecotypes. Each ecotype is slightly different from the others, but all belong to the same species. Two morphological ecotypes are widely recognized — lowland and upland. Upland types usually grow four to five feet tall and are adapted to relatively shallow soils. Lowland types, which grow up to 12 feet tall, are typically found on deep soils.

Switchgrass is a cross-pollinated species and has two common ploidy levels (number of chromosome sets). Upland types are generally octoploid and lowland types are usually tetraploid. Another variation has to do with the latitude where a particular switchgrass evolved. Those from the north tend to grow slowly in the late summer due to shortening day length, while those from the south usually grow longer into the autumn; thus, producing higher yields if otherwise adapted.

Some switchgrass ecotypes and varieties can grow well in the northern U.S. and in Canada where the growing seasons are relatively short (2 months), but days are long during the summer. Likewise, switchgrass can grow well in the southern U.S. and Mexico where the summer days are much shorter, but the growing season may last six to eight months. Switchgrass grows rapidly after breaking dormancy (March in Oklahoma) and slows when it begins to produce seed heads (July in Oklahoma). It needs at least one month in the north to reach its reproductive stage and may use three months in the south to finish its vegetative growth stage. If not harvested, switchgrass spends the rest of the growing season developing seed and storing energy in its crowns, roots, and rhizomes. This energy is needed to remain alive during its dormant period in the winter and for regrowth the next spring.

MISCONCEPTION: *Switchgrass grows well in dry areas with shallow, infertile soils and does not require fertilization or irrigation.*

FACTS:

- Alabama switchgrass yields approached 15 tons/acre. Nitrogen was applied at 100 lbs N/acre and there was abundant rainfall.
- Switchgrass production in Iowa uses the same nitrogen recommendation.
- Oklahoma does not currently have specific nitrogen recommendations, but switchgrass does not appear to be responsive to more than 50 lbs N/acre.
- In Oklahoma, the highest yields (8 tons/acre) occurred with 40 inches of precipitation; lower yields (6 tons/acre) occurred with 30 inches of precipitation, both on deep, fertile soils. Old stands of inferior varieties do not yield 6 tons/acre. Average yields of only 1 to 3 tons/acre should be expected on marginal sites.

Yield Potential

Adapted lowland switchgrass varieties, suited to the southern U.S., frequently produce more than 10 tons/acre/year of dry matter, but it is more reasonable to expect 5 to 8 tons/acre under commercial conditions. Upland types growing in shallow soils are likely to average yields of 1 to 4 tons/acre/year. With the longer growing season in the southern latitudes, biomass yields in the south can be expected to be higher than in northern areas. High yields for all crops are dependent on good moisture conditions. As a component of rangeland, switchgrass yields are closely related to its growing conditions and are much lower in low rainfall areas and in shallow soils.

Requirements

Even though switchgrass is tolerant of poor soil, droughty, and flooded conditions, it does have certain needs to produce economical biomass yields and persist for several years. High switchgrass yields have been recorded when the grass was grown under good conditions. These good conditions include a relatively deep soil with a pH level near neutral that can supply the nutrients needed for growth. Water must be available either through rainfall or irrigation. Temperatures must be relatively warm during the growing season, and the growing season must be long enough for the plants to fully develop.

Deep soil is needed for reasonable yields because it serves to store water and nutrients. Soil can store one-half inch to two inches of water per foot of depth. If the soil is only one foot deep, the available water will only be sufficient to maintain switchgrass for a few days

Figure 1-2. Stand of lowland switchgrass being established near Stillwater, Oklahoma.

or weeks without additional rain or irrigation. High yields are impossible without adequate water. An extremely acidic or alkaline soil may be toxic and may hold nutrients in forms that are unavailable to switchgrass. Soils near neutral (pH 5 to 8) are required for good growth and high yields.

Switchgrass is a perennial warm-season grass. This means it possesses mechanisms that allow it to tolerate cold temperatures during winter as dormant plants, but needs warm temperatures for growth. When temperatures are below 60° F or above 95° F, the growth of warm-season plants slows or stops. Plants can remain alive at these temperatures, but they grow slowly, if at all.

Switchgrass, along with other native species, is generally nonresponsive to applied nutrients compared to introduced grasses, such as bermudagrass, tall fescue, wheat, etc. However, high yields of switchgrass cannot be *sustained* if adequate N and other nutrients are not applied because removing the switchgrass biomass also removes significant amounts of these nutrients. To sustain production, the nutrients removed from the soil need to be replenished.

Seeds and Seedlings

The seed of switchgrass is small and much of it is dormant (will not germinate) right after harvest. However, aging, treating with water and chilling temperatures (stratification), or storing it in warm conditions will break this dormancy. Largely because its small seed size, switchgrass seedlings tend to be slow to develop, and suffer from weed competition.

Yield vs. Stand Age

Switchgrass tends to reach full yield the third year after planting; it produces one-quarter to one-third of full yield in the first year, and about two-thirds of full yield in the second year. When managed for energy production, it can be cut once or twice a year with regular hay or silage equipment and can be expected to last for fifteen years or more.

Figure 1-3. Switchgrass labeled with associated parts of the plant.

Switchgrass Plants

At maturity, widely-spaced switchgrass plants can be two feet or more in diameter at ground level. Switchgrass has a huge, permanent root system that may penetrate more than 10 feet into the soil, and weigh as much as the above-ground growth from one year (6 to 8 tons/acre). It also has many fine, temporary roots. All of these roots improve the soil by adding organic matter, and by increasing the soil water infiltration and nutrient-holding capacity. In addition to roots under soil, switchgrass has many small rhizomes, which are underground stems that store the energy and nutrients produced during one season and used in a later season.

Environmental Impact

Switchgrass has several environmental benefits. It provides habitat and food for many species of wildlife, including cover for deer, small mammals and birds, and a nesting place for wild turkey and quail. In addition, switchgrass provides a resting, hiding, and/or loafing environment for many other wildlife species.

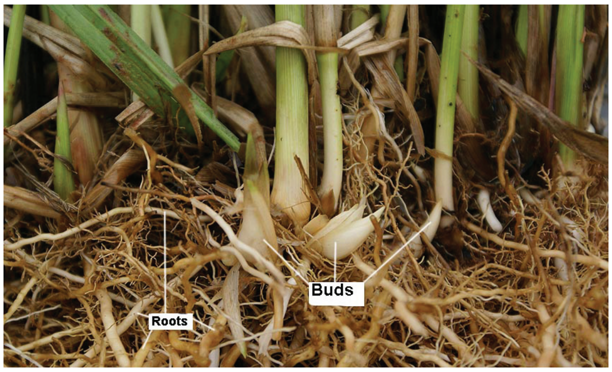


Figure 1-4. Extensive switchgrass tissues below ground aid in reducing soil erosion.

If used to produce energy, switchgrass may reduce the impact of climate change by replacing fossil fuels (coal, natural gas, and oil). When fossil fuels are burned, carbon is removed from below ground (gas and oil wells or coal mines) and released into the atmosphere as carbon dioxide (CO_2). This is a greenhouse gas that increases the risk of global warming. In contrast, switchgrass (like all other plants) removes CO_2 from the atmosphere and incorporates it into plant tissues, both above and below ground. Utilizing the above ground biomass as a renewable energy source provides potential to reduce CO_2 emissions.

In contrast to annual crops that are replanted every year, a switchgrass field may not be cultivated for 15 or 20 years, and the soil is never bare. Under these conditions, the risk of soil erosion by wind and water is minimal.

Realistic Expectations for Switchgrass in Oklahoma

2

Table 2-1. Biomass yield (tons/acre) for common switchgrass varieties adapted to the southern Great Plains grown at the Eastern Research Station near Haskell and South Central Research Station near Chickasha, 44- and 33-in. annual rainfall, respectively.

Varieties	*Ecotypes*	*7-yr Mean Yield*	
		Chickasha	*Haskell*
		(tons/acre/year)	
Alamo	Lowland	5.7	7.6
Kanlow	Lowland	5.8	7.9
Blackwell	Upland	4.6	5.7
Caddo	Upland	4.3	5.6

Yield Potential

Switchgrass has been correctly reported to be a high-yielding perennial native grass that will persist almost indefinitely. However, some biomass yields have been taken out of context and extrapolated to amounts that are not well founded.

Prediction of switchgrass biomass yield in Oklahoma is not an exact science since yields vary widely as a function of precipitation. The best data to assist with predictions comes from a seven-year study conducted at two Oklahoma locations near Chickasha and Haskell.

Average biomass yields for Alamo and Kanlow switchgrass varieties grown from 1994 through 2000 at the Eastern Research Station located near Haskell, OK (average annual precipitation 44 inches) were 7.6 and 7.9 tons/acre/year, respectively. Conversely, yield for the same varieties during the same period at the South Central Research Station located near Chickasha, OK (average annual precipitation 33 inches) was approximately 2 tons/acre/year less (see Table 2-1).

As noted in Chapter 1, there are important differences in biomass yield expectations based on switchgrass type. For instance, both Alamo and Kanlow switchgrasses are characterized as lowland types, whereas Blackwell and Caddo are upland types. As a general rule, the lowland types have greater yields than the upland types under similar conditions. However, in dry environments, the upland types, such as Blackwell switchgrass tend to be quite productive.

Figures 2-1 and 2-2 illustrate the year-to-year yield variation due to rainfall and the general differences between ecotypes. Yield generally follows the rainfall pattern. When

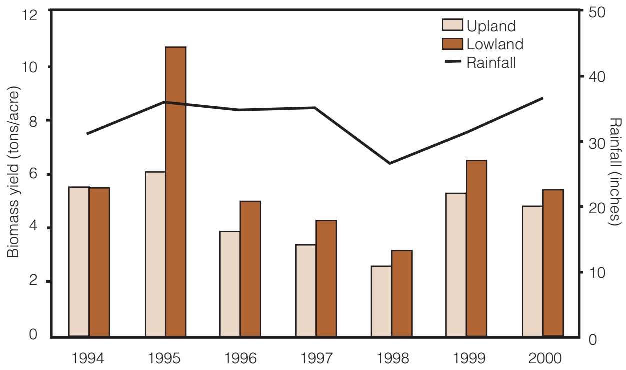


Figure 2-1. Mean biomass yield (tons/acre) for upland and lowland switchgrass types grown at Chickasha, OK.

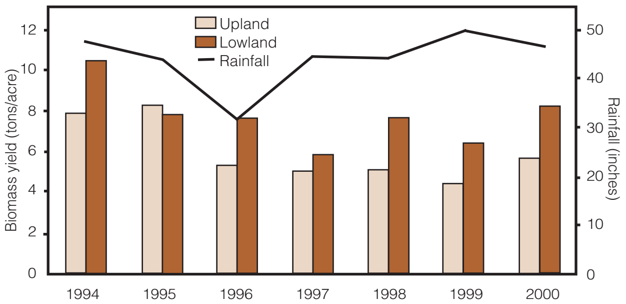


Figure 2-2. Mean biomass yield (tons/acre) for upland and lowland switchgrass types grown at Haskell, OK.

Table 2-2. Expected long-term yield (tons/acre/year) of upland and lowland switchgrass grown in different regions of Oklahoma that vary with rainfall, soil, and other environmental factors.

Ecotype	*Regions of Oklahoma*		
	East	*Central*	*West*
	Biomass yield (tons/acre/year)		
Lowland	5-13	3-12	2-4
Upland	2-9	2-6	1-3

yield during a particular year does not reflect the total rainfall, it is frequently due to distribution. Rain that comes after switchgrass heads will not contribute much to that year's yield, but may contribute to the next year's production.

Switchgrass biomass yields depend on environmental conditions that occur during the growing season. In Oklahoma, precipitation decreases from the southeast to the northwest and is almost always the limiting factor in determining switchgrass biomass yield. The yield expectations in Table 2-2 are based primarily on annual precipitation. The range of yields shows the effect of year and site conditions.

While rainfall is the primary determining factor affecting switchgrass yield, soil depth and fertility also are important. Soil depth determines, to a large extent, the amount of water that can be stored. One to two inches of water can be stored per foot of depth in most soils. If there is less than a foot of top soil to store water, regardless of the total rainfall, biomass yield will be limited with infrequent rain.

There is interest in using biomass harvested from erodible lands enrolled in a Conservation Reserve Program (CRP). Typically, these are restored grasslands planted with a mixture of warm-season native grass species, usually including switchgrass. Since these lands are classified as erodible, they also are highly variable in soil fertility, texture, and depth. In Oklahoma, biomass yields from plots established in a CRP have ranged from 0.35 ton/acre/year with zero lbs N/acre up to 0.80 ton/acre with 100 lbs N/acre with an average annual precipitation of approximately 25 inches. Conversely, studies conducted in South Dakota having monocultures of switchgrass in a CRP had biomass yields of 1.80 tons/acre with 20 to 25 inches of annual rainfall.

Stand Persistence

There is limited information available on long-term persistence of switchgrass stands. However, there are a few common sense production practices that would seem to be crucial to maximize persistence. Good agronomic practices that follow a reasonable fertility program and proper harvest management, will generally result in switchgrass stands that should be economically productive for at least 10 years.

3 Stand Establishment

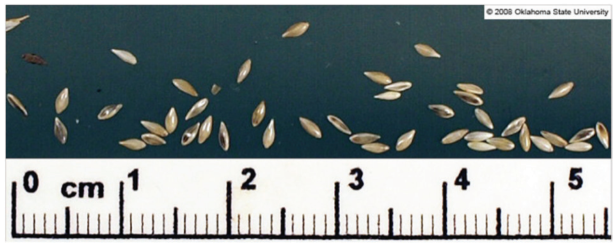


Figure 3-1. Switchgrass seed is small (2 to 3 mm or 1/10 of an inch) and smooth. The small size makes establishment difficult, but the smooth seed makes it easy to plant.

Switchgrass stand establishment can be a challenge primarily because of its small seed and slow seedling growth (Figure 3-1). Seedlings cannot emerge from more than a half inch deep, and once up and growing, many weeds grow much faster than switchgrass. The primary goal is to establish a stand with at least 20 seedlings per square foot as quickly as possible. Critical factors affecting this include: weed control before planting, seedbed preparation, seed quality (including dormancy), time of planting, method of establishment, and seeding rate. Other factors that affect rapid seedling establishment include variety choice, use of companion crops, and post emergence weed control.

Weed Control Before Planting

A weed-free seedbed is important for stand establishment because switchgrass seedlings do not compete favorably with weeds for water, sunlight, and nutrients. Clean tillage and firming the soil during the fall before planting is a good starting place. This should control both annual and perennial weeds, as well as provide a favorable environment for seed germination. If phosphorus fertilizer or lime is needed, it is a good idea to incorporate them in the fall before planting, leaving the seedbed in good condition. Light tillage may be needed during late winter or early spring, followed by rolling to firm the seedbed. Otherwise, weed control within a few days of planting is an important activity.

Seedbed

Traditionally, switchgrass is planted into a clean-tilled seedbed; however, there has been an increased interest in no-till establishment. Regardless of the seeding method, a critical factor for success is planting the seed into a moist, firm (not wet or hard) seedbed (Figures 3-2 to 3-4). This will allow for greater seed-to-soil contact, which is extremely important so

Figure 3-2. A good switchgrass seedbed is firm and has no large hard clods. The shoe impression did not sink into the soil (firm), yet it made a clear impression. For sandy soils, more small clods would be desirable to inhibit wind erosion.

Figure 3-3. Seed should be placed at a depth of ¼ to ½ inch and drill rows should not be so deep that soil is washed in on top of the seeds.

Figure 3-4. A no-till seedbed for switchgrass establishment.

the seed can absorb the moisture necessary for germination. Soil texture and soil depth within a site will determine the moisture availability, and thus influence the choice of planting method.

Seed Quality

Historically, the logical place to begin when planning a new forage seeding is to begin with the pure live seed (PLS) concept. The concept of using PLS is important because switchgrass seed often varies widely in quality and cost. Some seed lots can contain large amounts of inert material and undesirable seed. Because only live seeds are of value, the PLS method is the method used for buying, selling, and planting most forage seed.

It should be noted, the Oklahoma state seed law requires all seed sold must have a label including kind and variety, pure seed (percent), other crop seed (percent), inert matter (percent), and weed seed (percent). All noxious weeds must be listed in number per pound. Germination plus any dormant percentages and the date of test also are shown. The seed should be retested if the analysis is more than a year old. The labeler's name and city/state are required as well. Be sure to read the label and understand the quality of the seed.

Seed quality is a primary consideration for switchgrass establishment. Thus, it is important that switchgrass seed be tested at a reputable seed testing laboratory, so the seed germination percentage, seed purity, and percentage of dormant seed is known. Seed dormancy may be the most critical factor determining successful switchgrass establishment. Dormant seed is classified as live seed. However, a dormant seed will not germinate until the dormancy is eliminated. This can occur either with time or wet-cold stratification.

Time of Seeding

A general rule of thumb is to plant switchgrass during the same establishment window as corn; however, seeding date for switchgrass is somewhat variable and depends on the method. Seed germination for switchgrass occurs around 60° F and higher. Based on this, a normal time of seeding for switchgrass in the southern Great Plains is between April 1 and May 1. Nevertheless, it is not uncommon for dormant season plantings to occur from January through March. Seeding at this time is not for earlier germination, but rather an attempt to overcome some of the challenges of seed dormancy.

Planting Method

Switchgrass can be successfully established using several seeding practices. There are few definitive comparisons on whether a seedbed prepared using clean tillage or some form of minimum tillage is the better method for establishing switchgrass. If either method is used properly, they both should result in similar establishment under similar environmental and management conditions.

Clean-tilled seedbeds are the most widely used and have numerous advantages. The most notable advantage is it is easy to seed, since there is no plant residue on the surface. Likewise, accurate seed placement is more easily attainable if the seedbed is clean and firm. If the seedbed is not firm, the seed may be placed too deep and may not emerge following germination. A disadvantage to clean-tilled seedbeds is increased wind or water erosion potential, since there is no plant residue on the soil surface.

Mulch seedbeds can be used in environments that are prone to either wind or water erosion. Basically, the mulch crop is grown in place and not harvested. Additionally, most crops used in the management of mulch seedbeds are annuals. In most cases, it is not necessary to kill the mulch. The residue may control weed competition, but the greatest advantages are the potential for improved water retention through increased infiltration and decreased evapotranspiration.

There are disadvantages to using mulch seedbeds. It takes more time to grow the mulch and requires additional planning. Another disadvantage is seeding will be more difficult because of the mulch. To overcome this, it is crucial a no-till drill be used to plant through the mulch.

No-till establishment of switchgrass may include planting into small grain stubble after graze-out or haying. The small grain should be killed with herbicide to remove competition with the switchgrass seedlings. A herbicide can be applied within a few days of planting switchgrass and should control any weeds, as well as the small grain crop. Fertilizer and lime applications for switchgrass must be made before planting the small grain crop in this case.

Seeding Rate

Seeding rate recommendations for establishing switchgrass vary widely – from 2 pounds PLS/acre up to 10 pounds PLS/acre. The large differences in the recommendations can be attributed to seed quality, planting method, and environment. A goal for switchgrass establishment is to plant at least 20 PLS/square foot. To accomplish this goal, common seeding rate recommendations throughout the U.S., including the southern Great Plains, are 5 pounds PLS/acre for switchgrass. However, few recommendations have made any attempt to account for seed dormancy.

Seed dormancy is a significant issue to consider before planting switchgrass. Like most perennial grass seed, switchgrass seed exhibits varying degrees of dormancy that decreases as the seed ages. For example, seed less than one year old may have seed dormancy greater than 60 percent; whereas, the same lot of seed between one and two years old may have an insignificant amount of dormant seed.

Four options for deciding on the amount of switchgrass seed to plant are described, and all are related to managing seed dormancy at planting. None of the following establishment options precludes a reliable seed germination test or proper seedbed preparation. The recommended seeding rate using options 1, 2 and 3 is 5 pounds PLS/acre.

Figure 3-5. Established switchgrass plot near Stillwater, Oklahoma.

Option 1 is to plant seed that has been in storage for at least a year. The rationale is since seed dormancy declines over time, the older, dormant seed will usually germinate the following year. However, the seed that were germinable earlier may not germinate now. This option would only be recommended for seed with a high ratio of dormant seed to germinable seed. Additionally, it would be necessary to have adequate cool, dry storage space available.

Option 2 is a combination of wet-cold stratification of the seed prior to planting. This method requires adequate cold storage. The rationale is the combination of cold temperatures and elevated relative humidity (40° F at 50 percent relative humidity) reduces seed dormancy. However, wet-cold stratification is a somewhat risky process. Seed is placed in porous sacks (not water tight) and submerged up to 24 hours in water. Excess water is allowed to drain, and the seed is placed in cool storage (40° F at 50 percent relative humidity) for two weeks until planting. The primary drawback to using this option is that once it has been initiated, it is necessary to carry the process completely through to planting. At this point, a final word of caution is necessary. Seed that is allowed to dry out following wet-cold stratification may have a higher amount of dormant seed present than before.

Option 3 is a dormant season planting. The rationale for using this option would be similar to the cold-wet stratification except the natural conditions would reduce the dormancy. Planting time of this option would normally occur during winter months, usually in January or early February. Under most conditions during this time, seed will not germinate, but they will be ready to germinate as soon as soil temperatures are appropriate. Essentially they will be moist and stored in a cold soil.

Option 4 is the establishment based solely on germinable seed. Depending on the seed test, the seeding rate may be different than the recommended 5 pounds PLS/acre. Planting more seed than needed may make this practice cost prohibitive. This option may be best to consider with seed that has a high germination (greater than 60 percent) and low dormancy (less than 20 percent).

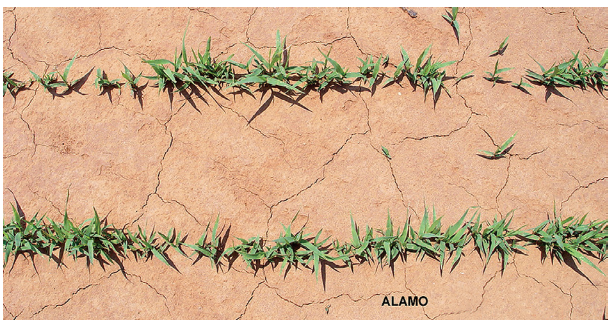


Figure 3-6. Alamo switchgrass seedlings emerging in somewhat dry conditions.

Table 3-1. Comparison of switchgrass seed lots on a pure live seed basis — 5 lbs PLS results in different potential stands depending on the percent quick germination.

	Low germination High dormancy	*High germination Low dormancy*
% Quick Germination	35	65
% Dormancy	58	28
% Purity	97	97
% Pure Live Seed	90	90
Quick Germination (seed/sq. ft.)*	16	29
Pounds PLS/acre	5	5
Bulk seed (pounds/acre)	5.6	5.6

*Assume 389,000 seeds/lb.

Table 3-2. Comparison of switchgrass seed lots on a germinable seed basis – results in a different amount of bulk seed needed to have 20 plants/sq. ft.

	Low germination High dormancy	High germination Low dormancy
% Germination	35	65
% Dormancy	58	28
% Purity	97	97
% Pure Live Seed	90	90
Quick Germination (seed/sq. ft.)*	20	20
Pounds PLS/acre	6.4	3.5
Bulk seed (pounds/acre)	7.1	3.9

*Assume 389,000 seeds/lb.

Seed lots with the same percent PLS may be very different. Even though the dormant seed is alive, it will not germinate quickly. Only the germinable seed will germinate in the near future. It is possible to have seed with high germination and low dormancy or low germination and high dormancy (and a similar PLS) that will behave differently under field conditions due to the number of germinable seeds per pound. Based on this, it may be possible to reduce the seeding rate for switchgrass with a high ratio of germinable to dormant seed.

The calculated seeding rate for switchgrass on a 5 lbs PLS/acre basis, has a large effect on the number of viable seeds planted per square foot (16 vs. 29 in Table 3-1). Using the germinable seed per square foot as a basis has a sizeable effect on seeding rate (7.1 vs 3.9 in Table 3-2). Even though the overall effect of seedling density appears small, it may be possible to reduce the seeding rate by at least 1 lb/acre with switchgrass seed that has a higher germination and lower dormancy. To have 20 seeds/sq. ft. that will germinate quickly, very different amounts of bulk seed is required (7.1 lbs/acre at 35 percent germination vs. 3.9 lbs/acre at 65 percent germination).

Variety Choice

Even with the national, regional, and local interest generated in using switchgrass as the cellulosic feedstock of choice, there are few varieties from which to choose. Since the 1940s there have been few switchgrass cultivars released in the U.S. (Table 3-3). Several field studies revealed southern cultivars as more productive than northern ones. However, southern varieties have winterkill problems if they are grown in regions more than one hardiness zone north of their origin. In Oklahoma, the lowland cultivars have a longer growing season than upland varieties.

Within the lowland ecotypes, southern lowland varieties such as Alamo and Cimarron have longer growing seasons than the northern lowland variety, Kanlow. Rainfall is an important factor for the selection of varieties to grow. It is believed lowland switchgrass can be grown in areas that annually receive more than 25 inches of rainfall. Upland varieties are less sensitive to drought than lowland varieties. In Oklahoma and adjacent areas in the southern Great Plains, Alamo, Cimarron, Kanlow, Blackwell, and Caddo are the logical choices. Generally, Alamo and Kanlow are better adapted to sites with loam and clay loam soils, and Blackwell and Caddo are better adapted to areas with lighter soils and eroded areas.

Use of Companion Crops

A companion crop is one planted with the desired perennial crop to provide protection from wind or water erosion. The choice of what crop to grow with switchgrass and not offer a high degree of competition is difficult because of switchgrass' slow growth and establishment. Small grains are cool-season species that do not grow long into the summer; however, they may be highly competitive. If a small grain is used as a companion crop, a very low seeding rate is recommended (perhaps only 3 to 5 lbs/acre). Only about one companion plant per two square feet is necessary to protect switchgrass seedlings.

Warm-season species such as sorghum or sorghum-sudan hybrids can be used, but they would have to be killed or risk excessive competition. A few (one per 2 to 3 square feet) soybean, mungbean, turnip, beet, etc. plants scattered over the field may help minimize erosion without undue competition.

Evaluation of Establishment Success

The ability to accurately evaluate stand establishment has little impact on the success of switchgrass production. However, it may alleviate some of the stress associated with establishing a slow-growing perennial grass. Correctly identifying switchgrass seedlings is crucial. The easiest way to correctly identify a

Table 3-3. Switchgrass Cultivar Releases in the U.S.

Ecotype	*Name/Year/Institutions*
Lowland	**Kanlow**/1963/Kansas Agricultural Experiment Station; Plant Science Division of ARS, USDA
	Alamo/1978/Plant Materials Center, Soil Conservation Service, Knox City, Texas; Texas Agricultural Experiment Station
	Performer®/2006/USDA-ARS; North Carolina Agricultural Research Service; North Carolina State University
	BoMaster®/2006/USDA-ARS; North Carolina Agricultural Research Service; North Carolina State University
	Cimarron/2008/Oklahoma Agricultural Experiment Station
Upland	**Grenville**/1940/Plant Materials Center, Soil Conservation Service, Spur, Texas
	Blackwell/1944/Plant Materials Center, Soil Conservation Service, Manhattan, Kansas; Kansas Agricultural Experiment Station
	Nebraska 28/1949/Nebraska Agricultural Experiment Station; USDA-ARS; Nursery Division, Soil Conservation Service
	Caddo/1955/Oklahoma Agricultural Experiment Station; Plant Science Research Division of USDA-ARS
	Summer/1963/South Dakota Agricultural Experiment Station
	Pathfinder/1967/Nebraska Agricultural Experiment Station; USDA-ARS
	Cave-In-Rock/1973/Plant Materials Center, Soil Conservation Service, Elsberry, Missouri; Missouri Agricultural Experiment Station
	Sunburst/1983/South Dakota Agricultural Experiment Station
	Trailblazer/1984/USDA-ARS and Nebraska Agricultural Experiment Station
	Shelter/1986/Soil Conservation Service; Cornell University; New York Department of Environmental Conservation Division of Fish & Wildlife, and the Pennsylvania Game Commission
	Forestburg/1987/Plant Materials Center, Soil Conservation Service, Bismarck, North Dakota; USDA-ARS; North Dakota, South Dakota, Minnesota, Agricultural Experiment Stations
	Dacotah/1989/USDA-ARS; Plant Materials Center, Soil Conservation Service, Bismarck, North Dakota; North Dakota and Minnesota, Agricultural Experiment Stations
	Shawnee/1995/USDA-ARS; the University of Nebraska; USDA-NRCS; IOWA Agricultural Experiment Station; Purdue Agricultural Research Program
	Carthage®/2006/NRCS New Jersey Plant Materials Center

switchgrass seedling is to properly identify any seed remnants attached to the emerged plant (Figure 3-1). This involves carefully extracting the seedling from soil without detaching the fragile, primary root system. Switchgrass seedlings generally have a smooth appearance and a purplish coloration on the lower portion of the stem (Figure 3-7).

A quantitative evaluation of establishment relies on some form of stand count methodology. An easy tool is to construct a 5x5 grid using a cattle panel (Figures 3-8 and 3-9). The grid is randomly placed in several locations throughout the field. A good rule of thumb is to evaluate no fewer than 4 locations per acre. The number of individual sections that contain at least one switchgrass seedling is counted. It does not matter if there is one switchgrass seedling per section or 15 switchgrass seedlings per section; it is counted as only one.

Figure 3-7. Switchgrass seedling (note attached seed coat). This seedling is well on its way to successful establishment. The primary (temporary) root system is still visibly attached to the seed coat. The permanent root system is in the early stages development.

Figure 3-8. A simple method for evaluating switchgrass seedlings stands may be no more than a section of a cattle panel, five cells long and five cells wide.

Figure 3-9. A grid section with approximately 10 switchgrass seedlings is counted as one.

Figure 3-10. A switchgrass stand during the establishment year. This type of weed pressure is not uncommon in seedling switchgrass stands.

Figure 3-11. The same switchgrass stand as shown in Figure 8, one-year post-planting. With good management and a little luck, it is possible to have a fully productive switchgrass stand in one year.

As an example, randomly place the grid in four locations and count the sections containing a switchgrass seedling. For each location, there are a total of 15, 14, 20, and 21 sections that contain at least one switchgrass seedling each, out of a possible 25 sections. The sum of these numbers, 70, is interpreted as a stand of 70 percent.

Weed Control During the First Summer after Planting

Switchgrass stands normally appear to be excessively weedy during the first summer (Figure 3-10), but frequently turn out to be a success (Figure 3-11). Large broadleaf weeds such as pigweed can be managed by mowing in mid to late summer. Sometimes, herbicides may be helpful in controlling certain weed problems.

General Recipe for Switchgrass Establishment - Summary

1. Clean-till in fall before spring planting.
2. Apply lime, P, and K based on soil test.
3. Clean-till in late winter and roller pack to firm the seedbed.
4. Wait for rainfall to germinate annual weeds.
5. Apply glyphosate within three days of planting to control weeds.
6. Without additional tillage, plant switchgrass ¼ to ½ inch deep in April.
7. Evaluate establishment two to three weeks post planting.
8. Apply labeled herbicides based on weed population or mow broadleaf weeds.
9. Burn stands the following spring.
10. Evaluate establishment.
11. Fertilize with 50 pounds N per acre at spring green up.

Soil Fertility and Fertilization

Many researchers have found switchgrass can be high yielding but not as responsive to applied nutrients as improved grasses, such as bermudagrass and tall fescue. However, most of those studies were based on short term observations (e.g., two to three years). Longer studies are needed to clarify how switchgrass uses nutrients.

High yields of switchgrass will not be sustained if adequate nitrogen (N) or other nutrients are not applied because it removes significant amounts of nutrients from the soil. Table 4-1 shows the average major nutrient content of mature switchgrass harvested in late fall or winter. The nutrient content of mature biomass is much less than that harvested earlier for forage. It is believed that N and other nutrients are translocated to the rhizomes for storage after switchgrass reaches maturity. Therefore, most nutrients will remain in the rhizomes for the following year's growth if the harvested portion is only the dry stems, leaves, and seed heads. However, the potential for optimum yield, maintenance of stand, maximum weed control, and sustainable production could be compromised if adequate soil fertility and soil pH are not maintained.

Table 4-1. Major plant nutrients removed by switchgrass when harvested at maturity as a biofuel crop.

Yield (tons)	*Nitrogen (lbs N)*	*Phosphorus (lbs P_2O_5)*	*Potassium (lbs K_2O)*
1	20	8	20
4	80	32	80
8	160	64	160

Nitrogen

Oklahoma does not have a specific fertilizer recommendation for switchgrass used for biofuel feedstocks, but several field fertility evaluations are under way. The most common recommendation for N is from 0 to 75 lbs per acre. Based on research done in the past, we recommend using the suggestions in Table 4-2 as an interim N recommendation for switchgrass production until a refined set of suggestions is developed based on field tests conducted in Oklahoma. The actual amount of N needed is the number from Table 4-2 minus soil residual N from a soil test report. The needed N should be applied when switchgrass is about 4 to 6 inches tall in the spring.

Nitrogen may increase competition from weeds during establishment. Therefore, no more than 10 lbs of N should be applied, and if the soil test shows more than 10 lbs of N, no N should be applied for switchgrass establishment.

Table 4-2. Nitrogen recommendation for switchgrass production.

Yield Goal (tons/acre)	*N (lbs/acre)*
1	0
2	40
3	80
>4	120

Table 4-3. Oklahoma phosphorus and potassium recommendations for native hay based on a soil test.

P Recommendation			K Recommendation		
Soil Test P Index	*Sufficiency %*	*P_2O_5/A*	*Soil Test K Index*	*Sufficiency %*	*K_2O/A*
0-10	50	40	0-75	40	40
10-20	80	20	75-125	70	30
20-40	95	0	125-200	85	20
>40	100	0	200-250	95	0
			>250	100	0

Phosphorus and Potassium

Our current phosphorus (P) and potassium (K) recommendations for native hay (Table 4-3) may serve as a reference for switchgrass until an improved scheme is developed. Both P and K are immobile nutrients and their recommendation is directly related to supplying power of the soil (sufficiency). If the soil is near 100 percent sufficiency, additional P or K fertilizer is not needed due to minimal response to applied P or K fertilizer.

MISCONCEPTION: *Fifteen percent of the U.S. agricultural land is unsuitable for farming. If all of it were planted to switchgrass, we could replace every gallon of gasoline with ethanol.*

FACTS:

- Currently, much of this land is in CRP, which is not highly productive for agriculture – with poor soil conditions, steep slopes, shallow, etc.
- Yields are much less than 6 to 8 tons/acre on steep, shallow soil with low fertility.

Figure 4-1. A truck spreading lime before establishment of switchgrass.

Table 4-4. Amount of lime recommended for switchgrass establishment. No lime is recommended when soil pH is 5.0 or higher, regardless of the buffer index.

Buffer Index	*Tons ECCE lime/A**
> 6.6	1.0
6.5	1.2
6.4	1.4
6.3	1.6
<6.2	2.0

*Tons of aglime/A = Tons ECCE lime required / %ECCE (This number is available from lime vendor).

Liming

In general, native, warm-season grasses tolerate moderate soil acidity, but liming is advantageous on very acidic soils, especially for switchgrass establishment. Liming is recommended if soil pH is less than 5; although no information is available on acid tolerance of common switchgrass varieties. The amount of lime needed is based on the buffer index of the soil (Table 4-4). Lime should be applied, and preferably incorporated before establishment. However, lime also can be applied on established stands although it takes longer to neutralize soil acidity.

Soil testing is needed for the above recommendations. Please see OSU Extension Fact Sheet PSS-2207 on how to collect a representative soil sample.

5 Pests

Few pests of economic importance have been recorded on switchgrass. However, this does not imply the crop will always be free from attack. As the acreage of switchgrass monocultures increases, a corresponding increase in pests is likely.

Diseases

Many fungal diseases have been reported for switchgrass including rusts, smuts, leaf spots, and crown and root rots. Most of these diseases however, have not been documented to be of economic importance. Like traditional crops, some fungal diseases will have the potential to affect biomass and seed production in the future. Rust (*Puccinia emaculata*) has been reported from numerous states, including Oklahoma. Rust spores are airborne and land on switchgrass plants. Under the right environmental conditions, the spores germinate and infect the plant. At first, light yellow flecks on the surface of the leaves or on culms can be observed. As the disease progresses, numerous lesions containing mature small brown spores erupt through the leaf surface. Rusts require an alternate plant host to complete its entire life-cycle, the alternate host(s) are plant species in the spurge family. Control is achieved by planting resistant varieties and possibly the use of foliar applied fungicides.

Another disease which has been documented to reduce switchgrass biomass is head smut caused by *Tilletia maclagani*. For a study conducted in Iowa, it was determined that head smut caused significant reductions in biomass yields and stand decline. The fungi survive as spores on seed and in infested soils. Spores infect coleoptiles before seedling emergence in the spring. The fungus grows through the plant and primarily colonizes at points of plant growth. In the developing seed head, the fungus displaces the kernel and upon maturity bunt balls emerge releasing spores which are dispersed by wind, rain and healthy seed. Control is facilitated through clean seed, plant resistance, and fungicide seed treatments.

In addition to fungal diseases, switchgrass has been found to be susceptible to some strains of barley yellow dwarf virus as well as Panicum mosaic virus. At this time, the importance of diseases caused by viruses, bacteria, and nematodes is not known, and there maybe biomass yield reductions attributable to these pathogens in the future.

Insects

Few insects have been identified as potential pests in switchgrass. Grasshoppers are known to feed on switchgrass, but the extent of their damage has not been quantified; however, it is known to be highly variable from year to year. Commonly found insects on switchgrass include aphids, leafhoppers, blister beetles, chinch bugs, grasshoppers, stem bores, and wireworms. Several beneficial insects also have

Table 5-1. In a single field near Haskell, Okla. the following weeds were identified during the establishment stage of a switchgrass planting.

Grasses	*Broadleaf and other weeds*
Crabgrass (*Digitaria* spp.)	Pigweed (*Amaranthus* spp.)
Goosegrass (*Eleusine indica*)	Nutsedge (*Cyperus esculentus*)
	Carpetweed (*Mollugo verticillata*)

Table 5-2. In a single field near Stillwater, Okla., the following list of weeds were identified during the establishment stage.

Grasses	*Broadleaf weeds*
Bermudagrass (*Cynadon dactylon*)	Black and silverleaf nightshade (*Solanum* spp.)
Crabgrass (*Digitaria* spp.)	Curly dock (*Rumex crispus*)
Foxtail (*Setaria* spp.)	Field bindweed (*Convolvulus arvensis*)
Goosegrass (*Eleusine indica*)	Goathead or puncture vine (*Tribulus terrestris*)
Johnsongrass (*Sorghum halepense*)	Honeyvine milkweed (*Ampelamus albidus*)
Signalgrass (*Brachiaria platyphylla*)	Honey locust (*Robinia* spp.)
Stinkgrass (*Eragrostis cilianensis*)	Horsenettle (*Solanum carolinense*)
Ticklegrass (*Agrostis* spp.)	Morningglory (*Ipomoea* spp.)
Witchgrass (*Panicum* spp.)	Nutsedge (*Cyperus esculentus*)
	Passionvine (*Passiflora* spp.)
	Pigweed (*Amaranthus* spp.)
	Virginia creeper (*Parthenocissus* spp.)

been reported including ants, rove beetles, ground beetles, parasitoid wasps, and spiders.

Weeds

Both weedy grasses and broadleaf weeds can be serious problems during switchgrass establishment, but usually only minor problems after the first year. The array of weeds found in any field depends on the previous use of the land and nearby plants whose seeds may have blown or washed onto the site.

In a field near Stillwater with an 11-year old stand of Kanlow switchgrass, rough fleabane (*Erigeron strigosus*) was the only weed in the early growing season, and annual bromes were the only cool-season weeds found after biomass harvest. Both were shaded out by switchgrass growth and neither affected production. During the establishment phase of a stand, the presence of weeds may be highly variable as illustrated in Tables 5-1 and 5-2.

MISCONCEPTION: *In the future (10 to 20 years), switchgrass yields will increase beyond their current potential.*

FACTS:

- Switchgrass is a perennial and should be resown every 10 to 15 years.
- Yields are currently dependent on differences in environmental conditions with average yields of between 5 to 10 tons/acre on good soils. Marginal sites yield much less.
- Historically, there has been little success with increasing biomass yields in herbaceous crops.
- Little research has been devoted to increasing switchgrass yields (compared to many of our row crops) and no research yet indicates substantially higher yielding cultivars will be available.

6 Harvesting

Season

Date of switchgrass harvest affects biomass yield and quality, and both of these affect biofuel production and its associated economics. Balancing these components may vary depending on conversion systems. A single harvest after flowering is the preferred timing, but harvesting any time between early flowering and just after frost generally produces the highest switchgrass biomass yield.

If harvest of the standing crop is delayed until the next March, a decrease in biomass yield could reach 40 percent. The main reasons for this decrease are: 1) decrease in tiller weight, 2) increased biomass lost during the harvesting process, and 3) losses due to weathering over winter. Spring harvesting, however, provides habitat for wildlife during winter and may be preferred over burning to clean up the field.

Number of Harvests

No more than two harvests per production season should be taken or a reduction in biomass yield and stand density could occur. Switchgrass stubble height should be no less than 6 inches. The tall stubble helps maintain effective growing points and reduces tire punctures by allowing equipment tires to push over the stubble. This cutting height also helps trap winter precipitation in the form of snow and lessens the chance of winter kill. Switchgrass stand survival, vigor, and yield can be increased by harvesting only during the recommended harvest windows and at the appropriate stubble height.

Equipment and Storage

Switchgrass can be harvested with traditional hay swathers and balers — large round bales or large square bales (See Figures 6-1 and 6-2). The preferred package is the large square bales because they are easier to manage for transportation and long-term storage. Baled switchgrass may be stored unprotected outside in dry areas. In areas with high rainfall (> 30 inches), a significant amount of dry matter loss should be expected. Storage in barns reduces biomass losses but increases overall production costs.

Quality

Switchgrass quality is another important trait affecting efficient biofuel production.

Figure 6-1. Windrows made with a traditional hay swather.

Figure 6-2. Harvesting switchgrass in a windrow with a round baler.

Lignocellulose yield is important for fermentation and gasification processes and is favored by fall harvest due to the high biomass yields. For direct combustion as pellets, spring harvest is favored due to its lower mineral concentration because of leaching during winter. Moisture should be 15 percent or less to facilitate baling and transportation. This also ensures a higher quality feedstock. Switchgrass that is co-fired in coal plants is burned at a moisture percentage of 12 to 13 percent. As with hay, the lower the moisture content, the higher the handling losses while swathing and baling.

Grazing and Hay Production

A possible option is to graze or hay switchgrass in the spring when switchgrass plants have substantial growth and the forage nutritive value is relatively high. After the spring harvest, subsequent regrowth could be harvested for biomass at the end or after the growing season. This dual purpose option of switchgrass may reduce biomass yield, but could increase farmers' income, especially in the early stage of introducing switchgrass into the existing farming landscape.

Grazing and haying are traditional harvest methods for native perennial grasses and may remain important for switchgrass grown in monocultures. While the switchgrass biofuels industry is being developed, grazing may offer opportunities to some producers who do not want to devote land for two years without opportunities for revenue. Switchgrass forage has good quality for grazing before it begins heading. Once seed heads are formed, nutritive value for grazing or hay falls dramatically.

Spring-planted warm-season grasses such as switchgrass, are slow to establish and grazing is not usually an option during the seeding year. With good weed control during the seeding year, grazing may be an option the following year. If there was no effective weed control or weeds were just clipped the first year, it may take two years to realize any appreciable grazing. This underscores the importance of beginning with a weed-free seedbed.

It may be possible to use switchgrass as a forage crop early in the season and use the regrowth for biofuel, but care must be exercised. Regrowth potential following grazing for tall, upright plants, such as switchgrass, is low. This is because the growing points are easily removed. Any new growth must come from the crown of the plant.

There are two critical heights to remember about grazing switchgrass.

- The first — grazing should not begin until switchgrass reaches at least 18 inches tall.
- The second — it is important to leave a stubble height of no less than 6 inches when grazing or haying.

7 Processing Switchgrass to Biofuel

Biofuels are defined as liquid, gaseous, or solid fuels derived from recently dead biological material and are distinguished from fossil fuels, which are derived from long dead biological material. Theoretically, biofuels can be produced from any biological carbon source (i.e., biomass waste and non-food energy crops). Various plants and plant-derived materials are used for biofuels manufacturing. Switchgrass belongs to the family of cellulosic feed stocks that might not compete with food crops and have higher energy output per unit input compared to corn. Switchgrass can be processed and used as liquid, gaseous, or solid fuel. Fuels derived from non-grain sources, such as switchgrass, are known as advanced biofuels.

Liquid Biofuels

Ethanol

Ethanol is the main liquid biofuel and can be produced from switchgrass through the two major processes described below.

Biochemical Conversion: In cases of corn grain and sweet sorghum stalks, sugars are directly fermented to ethanol by adding enzymes and yeast. Cellulosic feedstocks are more difficult to break down into fermentable sugars than starch- or sugar-based feedstocks.The cellulosic biochemical conversion process requires additional steps (see Figure 7-1). Two key steps are biomass pretreatment and cellulose hydrolysis. During pretreatment, the hemicellulose part of the biomass is broken down into simple sugars and removed for fermentation. During cellulose hydrolysis, the cellulose part of the biomass is broken down into the simple sugar, glucose.

Xylose is the most prevalent pentose sugar released by the hemicellulose hydrolysis reaction. In this step, xylose is fermented, using *Zymomonas mobilis* or other genetically engineered bacteria. The glucose fermentation reaction is caused by yeast or bacteria, which feed on the sugars. As the sugars are consumed, ethanol and carbon dioxide are produced. Lignin and other byproducts of the biomass-to-ethanol process can be burned to produce electricity required for the ethanol production process. Burning lignin actually creates more energy than is needed, and selling electricity may help the processes economics.

Thermochemical Conversion: Switchgrass also can be used to produce ethanol using thermochemical processes. In this approach, heat and chemicals are used to break biomass into syngas (a mixture of carbon monoxide and hydrogen) and reassemble it into

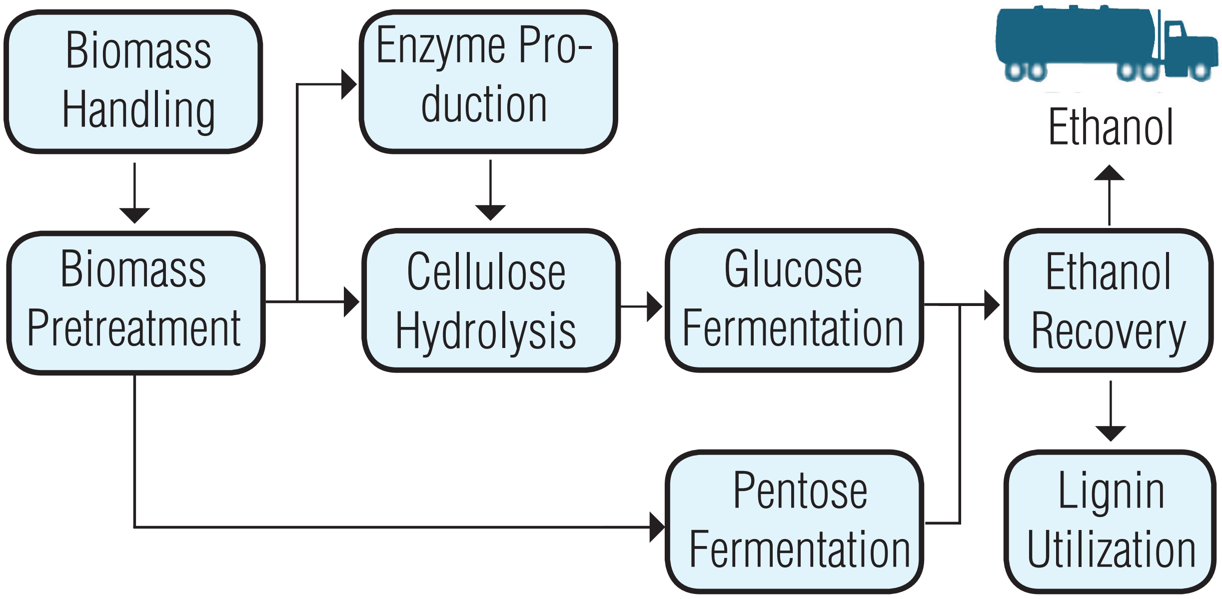


Figure 7-1. Schematic of a Biochemical Cellulosic Ethanol Production Process.

(Source:http://www.afdc.energy.gov/afdc/ethanol/production_cellulosic.html)

products such as ethanol, as illustrated in Figure 7-2.

Methanol

As an engine fuel, methanol has similar chemical and physical characteristics as ethanol. It is predominantly produced by steam reforming natural gas to create a synthesis gas, which is then fed into a reactor vessel in the presence of a catalyst. This process then produces methanol and water vapor. Although a variety of feedstocks can be used to create methanol, today's economics favor the use of natural gas.

Biobutanol

Like ethanol, biobutanol is an alcohol that can be produced through processing of domestically grown crops such as corn, sugar beets, and other biomass such as fast-growing grasses, and agricultural waste products. The ability to produce butanol from biomass

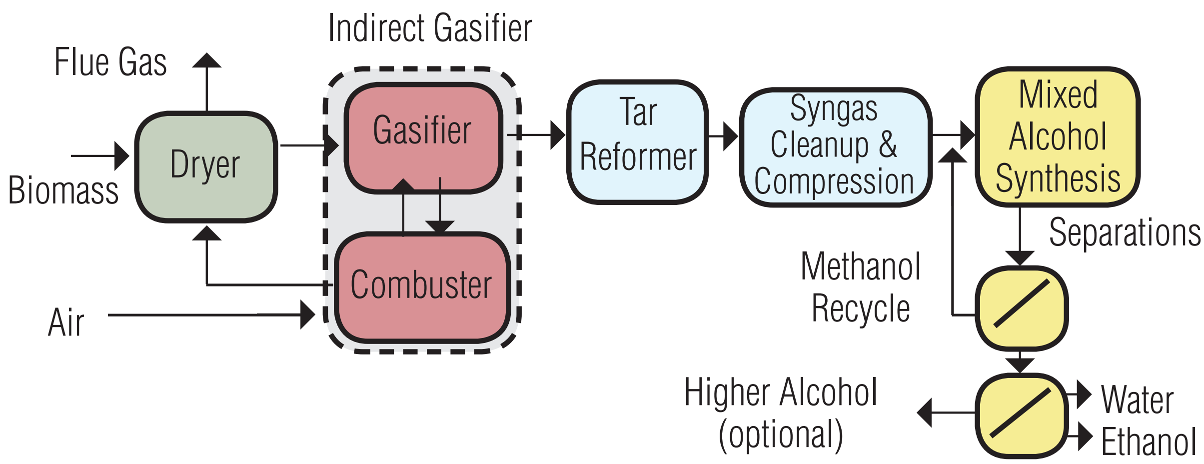


Figure 7-2. Schematic of a Thermochemical Cellulosic Ethanol Production Process.

(Source:http://www.afdc.energy.gov/afdc/ethanol/production_cellulosic.html) sources via fermentation has existed since the early 1900s. However, these older biobutanol processes are more expensive than today's petrochemical production processes. Today, butanol is produced almost entirely from petroleum. Renewed interest in butanol as a sustainable vehicle fuel has led to the development of improved biobutanol production processes. DuPont® and BP® are making biobutanol the first product of their joint effort to develop, produce, and market next-generation biofuels.

Biodiesel

Another important liquid fuel worth mentioning is biodiesel, even though it is not derived from cellulosic feedstocks. It will play a major role in reducing foreign oil dependency as it can be used in trucks and freight vehicles. In the U.S., most biodiesel is made from soybean oil or recycled cooking oils. Animal fats, vegetable oils, and other recycled oils can also be used to produce biodiesel, depending on their costs and availability. In the future, blends of all kinds of fats and oils may be used to produce biodiesel. The main reaction for converting oil to biodiesel is called transesterification. This transesterification process reacts an alcohol (like methanol) with the triglyceride oils contained in vegetable oils, animal fats, or recycled greases forming fatty acid alkyl esters (biodiesel) and glycerin. The reaction requires heat and a strong base catalyst, such as sodium hydroxide or potassium hydroxide. The byproducts include methanol and the base catalyst that can be reused in the process. Another byproduct is glycerin that can be for sale to the pharmaceutical and cosmetic industries.

Gaseous Biofuels

Hydrogen

Hydrogen has the potential to revolutionize transportation and, possibly, our entire energy system. It is the simplest and most abundant element in the universe, but it is not available in its free form (H_2). Hydrogen is locked up in enormous quantities in water (H_2O), hydrocarbons (such as methane, CH_4) and other organic matter. Hydrogen can be produced from fossil fuels, biomass, and even by electrolyzing water. Producing hydrogen with renewable energy and using it in fuel cell vehicles holds the promise of virtually pollution-free transportation and independence from imported petroleum. Hydrogen also can be used to fuel internal combustion engines and fuel cells, both of which can power low- or zero-emissions vehicles. Major research and development efforts are aimed at making hydrogen vehicles practical for widespread use.

Biopropane

Propane, also known as liquefied petroleum gas (LPG) is used by many fleets. It has a high energy density, giving propane vehicles good driving range, and propane fueling infrastructure is widespread. Researchers at Massachusetts Institute of Technology have developed an efficient chemical process for making propane from sugars. Biopropane conversion has a good energy balance: little fossil fuel needs to be burned during production. The reaction does not require the input of a large amount of energy because the heat that is key to the biopropane conversion is recoverable using a heat exchanger, a device that transfers heat in and out of a fluid

Solid Biofuels

Pellets

Switchgrass has been identified as a promising pelleting feedstock as it facilitates higher throughput rates and requires less energy for crop drying than wood. Although switchgrass is a higher cost feedstock to procure than wood residues, it could become an economical biofuel. The overall energy balance of switchgrass pellets is 14.6:1, which includes energy for switchgrass production, transportation to the conversion facility, preprocessing, pelleting, and marketing (see Table 7-1). A growing number of pellet stove and boiler suppliers developing advanced combustion appliances can burn grass pellets. An opportunity exists

Table 7-1. Energy associated with switchgrass pellet production.

Process	*Energy (GJ/ton)*
Switchgrass establishment	0.028
Switchgrass fertilization and application	0.460
Switchgrass harvesting	0.231
Switchgrass transportation	0.072
Pellet mill construction	0.043
Pellet mill operation	0.244
Management, sales, billing and delivery of pellets	0.193
Total Energy Input	1.271
Total Energy Output	18.5
Energy Output/Input ratio	14.6

(Source:http://www.reap-canada.com/online_library/feedstock_biomass/15%20Assessment%20of.PDF)

to develop a decentralized local industry. Individuals or groups of farmers can establish their own pelleting or briquetting factories. In some locations existing alfalfa or wood pellet plants can be utilized.

Figure 7-3. Swithgrass pellets.

Pelleting grasses is not difficult, provided the following conditions are met: the material needs to be ground to pass through screens of 5/64 inch or smaller; it needs to be treated with high temperature steam of at least 200° F; and an appropriate sized pellet die needs to be utilized, typically with a thickness of 2 $^1/_4$ inch to produce 1/4 inch pellets. Harvesting switchgrass for pelleting involves mowing in winter and harvesting and pelting in spring. This allows time to leach the excess potassium and chlorine from the biomass, thereby reducing the particulates emission.

Switchgrass pellets and coal co-firing in power plants is gaining popularity due to the low-cost and technologically simple method for reducing CO_2 emissions. Recent estimates show that co-firing 189 million dry tons of switchgrass with coal in the existing U.S. coal-fired electricity generation fleet, can mitigate approximately 256 million dry tons of carbon dioxide per year, representing a 9 percent reduction in 2005 electricity sector carbon dioxide emissions. The savings in greenhouse gas emissions are considerable because pellets have much lower emissions than coal, liquid natural gas, and natural gas, offering net offsets of 86 percent to 91 percent.

MISCONCEPTION: *Switchgrass is cheaper to produce as a feedstock than corn for producing ethanol.*

FACTS:

- The processes for conversion of cellulose in switchgrass stems to a usable clean fuel have not been proven on a large scale; thus, the economics remain unknown.
- Consideration must be given to:
  - o Fuel prices
  - o Yield (higher yields have cheaper production costs per unit of production.)
  - o Transportation costs. Switchgrass is bulky and expensive to haul.
- Overall it may be more than, less than, or equal to corn-based ethanol.

8 Environmental Impacts

Soil Erosion Control

Planting switchgrass on croplands dramatically reduces soil erosion potential compared to annual row crops. The perennial nature of the crop provides for year-round protection of the soil surface from erosive forces of wind and rainfall after it is established. This is especially true for marginal land, which can be highly erosive.

During establishment, care should be taken to minimize soil erosion. Switchgrass seedlings require one to two weeks to emerge, even under ideal conditions. This presents a real possibility of excessive soil erosion if sufficient residue is not maintained during establishment. Therefore, it is recommended some crop residue remain on top of the seedbed for erosion control. Furthermore, success with direct seeding of switchgrass into previous crop stubble has been reported, which would provide for optimum erosion control during establishment. Utilization of a non-competitive companion crop with switchgrass also provides for erosion control and may provide a level of weed suppression.

Carbon Sequestration and Greenhouse Gas Offsets

The soil carbon content of cropland soils has been reduced through long-term cultivation. Cultivation enhances soil aeration and accelerates the break down of soil organic matter, the main source of soil carbon. Growing switchgrass provides an opportunity to sequester carbon in soil because tillage is removed from the system. Also, perennial grasses such as switchgrass can deposit organic matter deep within the soil profile as roots expand into the subsoil for nutrients and water.

Sequestration of carbon in soils removes CO_2 from the atmosphere, which is considered a greenhouse gas contributing to global climate change. Its reduction in the atmosphere is one benefit of utilizing switchgrass as a fuel source to offset CO_2 emissions from the combustion of fossil fuels. Much of the offset results from the fact that ethanol use reduces gasoline combustion. However, some CO_2 offset results from sequestration of carbon in soils, particularly in soils cultivated prior to switchgrass establishment. Establishment of switchgrass on Conservation Reserve Program (CRP) land or rangeland, results in little or no net increased soil carbon sequestration because these systems contain relatively high levels of soil carbon; therefore, carbon accumulation is limited compared to previously cultivated land.

CRP Opportunities and Concerns

There is much debate about the role of CRP lands within the developing biofuels industry. Many wildlife conservation groups are concerned that a biofuels industry centered on grain-based ethanol will cause CRP lands to be converted to annual grain crops, which will reduce wildlife habitat quality. A cellulosic biofuel industry fed by perennial grasses such as switchgrass could provide for a good compromise because switchgrass, even when grown in a monoculture, is reported to provide higher quality habitat than annual cropping systems. In addition, switchgrass production provides for soil conservation and minimizes nutrient runoff to surface water bodies; thereby, providing the benefits originally intended for the CRP program.

MISCONCEPTION: *Switchgrass is good for the environment because it adds organic matter and carbon to the soil.*

FACTS:
- Switchgrass captures great amounts of carbon from the air and converts it to organic matter as it grows; however, this last only as long as the plants are alive.
- When a stand is destroyed and the land is plowed, the organic matter quickly breaks down and the carbon is released into the atmosphere as carbon dioxide.

Biodiversity and Wildlife Habitat

Switchgrass can provide habitat and food for many species of wildlife, including cover for large and small mammals, and a nesting place for wild turkey and quail. Even as a monoculture, it is better suited than annual grain crops to provide cover, forage, and nesting areas for native species. The final impact of switchgrass planted for biofuel production on biodiversity depends on how it is managed. Converting CRP lands that currently have mixed native grass stands to monocultures of switchgrass may reduce wildlife habitat.

9 Seed Production

Photo courtesy Les Crall, Producer and Southwestern Oklahoma State University.

A large amount and consistent supply of seed is needed if switchgrass becomes a major cellulosic biofuel crop in the U.S. Good management practices are critically important for producing good yields of high quality seed. Most switchgrass seed is produced in the central and southern Great Pains, including Oklahoma, as part of traditional farming practices. The dry weather in August and September in Oklahoma is conducive for producing high-quality switchgrass seed.

Burning crop residues, which helps switchgrass green up early, can be performed in February each year before switchgrass starts to grow. Burning fields also helps control the few weeds in mature stands (Figure 9-1). Fertilization with 50 to 100 lbs N/acre each year is important for good seed production. Fertilizer works best when applied in the spring after plants have started to grow for two or three weeks. Phosphorous and potassium should be applied if soil tests indicate available soil P and/or K are low. Generally switchgrass does not need irrigation, but some supplemental water may be beneficial during the period of seed development under drought conditions.

In Oklahoma, emergence of switchgrass seedheads varies, primarily due to different ecotypes and varieties. For example, emergence of seedheads of upland varieties starts in late June or early July. However, inflorescences of lowland varieties come out in August. Normally, upland switchgrass seed matures in August, while lowland switchgrass seed is ready for harvest at the end of September or early October (Figure 9-2). Additionally, the variety Kanlow seed matures about two


Figure 9-1. Burning residue in late winter after directly combining seed the previous fall.


Figure 9-2. A switchgrass panicle (seedhead) with ripe seed.

Figure 9-3. Switchgrass growing in 40-inch rows for seed production.

Figure 9-5. Switchgrass seed crop may be windrowed with a swather.

weeks earlier than Alamo, both lowland switchgrass types.

Switchgrass seed can be produced in solid-seeded stands or in specialized row plantings (Figure 9-3). Row plantings tend to produce more seed than solid stands. Row widths of 15 to 40 inches can be highly productive. Switchgrass plants are likely to lodge if row spacing is less than 12 inches. Likewise if rows are wider than 45 inches, seed yields in the first few years tend to be relatively low.

Switchgrass seed is harvested by directly combining the standing maturing crop (Figure 9-4) or by first windrowing the crop (Figure 9-5) and then combining the windrowed crop after the panicles have dried for a few days.

The optimum time to harvest is when most of the spikelets have mature seeds and a few seeds are beginning to shatter from seedheads. The main advantage to direct combining is one less operation across the field is required. The windrow harvesting method allows cutting while stems are still green and before seed begins to shatter. Seed shattering in some lowland switchgrass varieties can result in total seed loss (Figure 9-6). Following the harvest, seed must be conditioned in preparation for sale. Conditioning involves removal of trash, weed seeds, other crop seeds, and other materials. Seed yield of switchgrass varies from 150 lbs/acre in the first year post establishment, to approximately 300 lbs/acre when

Photo courtesy Les Crall, Producer and Southwestern Oklahoma State University.

Figure 9-4. Switchgrass seed crop may be directly combined in the field.

Figure 9-6. Alamo switchgrass seed is completely shattered from inflorescences by the third week in November in Stillwater, Okla.

stands are fully established. Under ideal conditions, seed yields could potentially be much higher (Figures 9-7, 9-8, and 9-9).

To assure the variety identity, genetic purity, and high quality of seed sold to consumers, seed producers are encouraged to produce certified switchgrass seed. Oklahoma Crop Improvement Association (http://okcrop.com/) is the seed certifying agency in the state.

Figure 9-7. View from combine of switchgrass as it is harvested for seed next to an area already harvested.

Photo courtesy Les Crall, Producer and Southwestern Oklahoma State University.

Figure 9-8. View from combine of switchgrass as it is harvested for seed, next to an area already harvested.

Photo courtesy Les Crall, Producer and Southwestern Oklahoma State University.

Figure 9-9. Switchgrass stubble after seed harvest.

10 Other Switchgrass Information Sources

Blade (Ceres) - Planting & Managing Switchgrass as a Dedicated Energy Crop
http://www.bladeenergy.com/Bladepdf/Blade_Switchgrass_Crop_Guide_2009.pdf

Florida - Production of Biofuel Crops in Florida: Switchgrass
http://edis.ifas.ufl.edu/AG296

Iowa - Management Guide for the Production of Switchgrass for Biomass Fuel in Southern Iowa
http://www.extension.iastate.edu/Publications/PM1710.pdf

Missouri - Big Bluestem, Indiangrass and Switchgrass
http://extension.missouri.edu/explore/agguides/crops/g04673.htm

Nevada - Northwestern Nevada Switchgrass Establishment, Production Costs and Returns, 2008
http://www.unce.unr.edu/publications/files/ag/2008/sp0812.pdf

Ontario - Switchgrass Production in Ontario: A Management Guide
http://www.reap-canada.com/online_library/grass_pellets/2007%20SG%20production%20guide-FINAL.pdf

Rutgers (NJ) - Switchgrass Production and Use in New Jersey
http://njaes.rutgers.edu/pubs/publication.asp?pid=FS1075

South Dakota - Management Guide for Biomass Feedstock Production from Switchgrass in the Northern Great Plains
http://agbiopubs.sdstate.edu/articles/SGINC2-07.pdf

Tennessee - Growing and Harvesting Switchgrass for Ethanol Production in Tennessee
http://agroecology.clemson.edu/switchgrass/resources/utennessee_switchgrass.pdf

USDA - 1993. Index of Species Information: *Panicum virgatum*
http://www.fs.fed.us/database/feis/plants/graminoid/panvir/all.html

USDA NRCS - Switchgrass (Panicum virgatum)
http://agroecology.clemson.edu/switchgrass/resources/switchgrass_fact_sheet_nrcs_2003.pdf

Virginia - Planting and Managing Switchgrass for Forage, Wildlife, and Conservation
http://www.ext.vt.edu/pubs/forage/418-013/418-013.pdf

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