CHAPTER 4

Growing Perennial Forages for Biomass

Matt A. Sanderson and Igathinathane Cannayen

Perennial forage crops have been rediscovered as a "green" source of energy. Recent attention given to converting forage plants into ethanol to fuel vehicles or burning it to generate electricity has captured society's interest. It should be remembered, however, that before World War II, forages provided the fuel for the draft animals that pulled plows and transported goods and people. This chapter presents an overview of the utilization technologies applicable to plant-based biomass and provides agronomic and management information about bioenergy forage crops.

Biomass and its sources

Biomass, as a feedstock, in a broad sense refers to the material obtained from plants (micro and macro; non-food and food) and manure from animal production (e.g. biogas production). Sources of biomass can be categorized as (1) primary—derived from agriculture and forestry (e.g. dedicated grasses and trees, crop residues), (2) secondary—derived from industrial processing (e.g. sawdust, food wastes), and (3) tertiary—derived from wastes of product final consumption (e.g. urban wastes). Various utilization pathways ultimately transform biomass into three major groups of products: biofuels, bioenergy or bioproducts.

Plant biomass refers to the plant matter obtained from annual, perennial or woody crops. *Cellulosic biomass* refers to the fibrous component of the crop (e.g. leaves and stems) as opposed to the starch or oil in grain. *Biofuel* means solid or liquid fuels obtained from biomass via various conversion processes. The major emphasis on biofuels at present is transportation fuels for either *blending* (e.g. ethanol—mixed with gasoline) or *drop in* (e.g. biodiesel, jet fuel—directly used) fuel types. *Bioenergy* means any form of energy obtained from biomass, with the present interest in the thermal energy generation for various heating applications.

The benefits of biomass energy are reduced dependence on imported energy, low carbon footprint, mitigation of greenhouse gases and sustainable use of marginal lands for bioenergy crop production. The current criticism of biofuels focuses on the lower system and cost efficiencies of biomass technology compared with fossil fuels, especially when the environmental benefits are not taken into account.

Biomass utilization pathways

Various established and new technologies of biomass utilization are described (Fig. 1). Biomass in the raw form is very bulky, does not flow through processing machines and is not readily accessible to downstream processing agents. Biomass

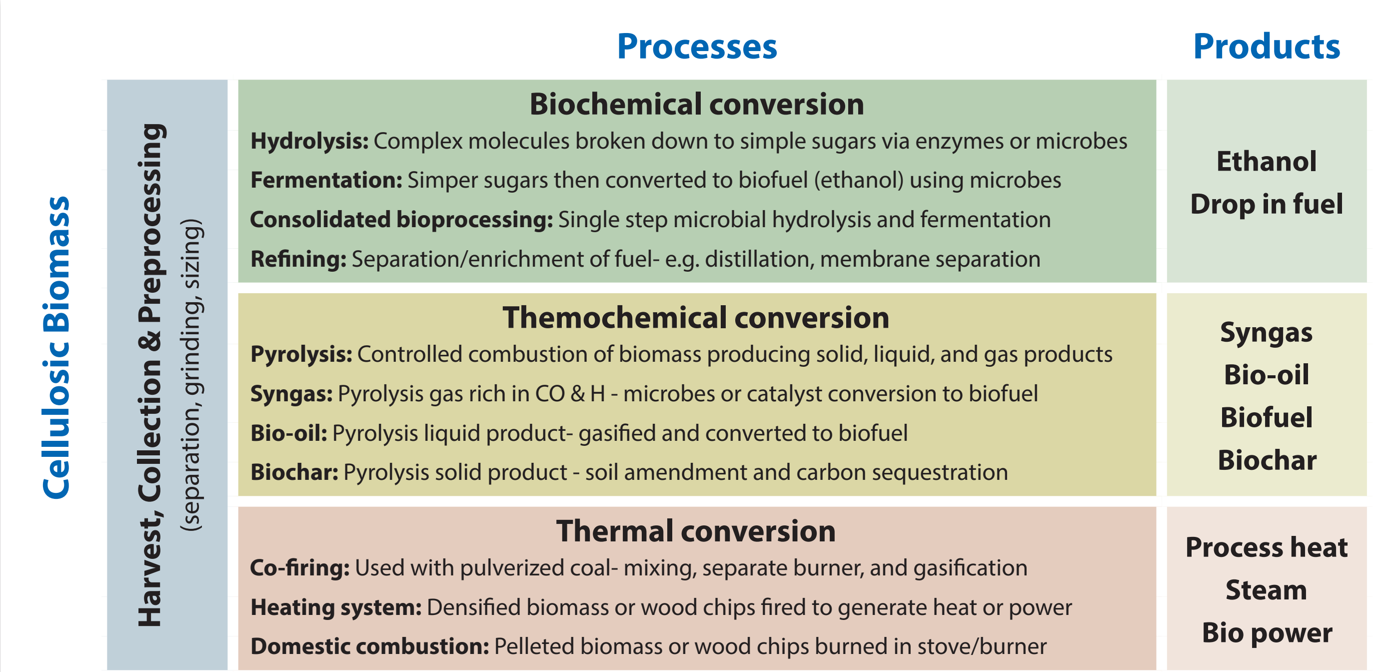

Figure 1. Cellulosic biomass energy conversion pathways showing processes and products.

processing includes a preparatory *upstream* and a conversion *downstream* process. Upstream processing enables biomass to be efficiently transported and utilized in the downstream processes. The major preparatory operations include separation of desirable biomass into anatomical components, and grinding and sizing to the optimum particle size for different downstream utilization processes (≤2.5 cm or 1 in).

There are three main routes for converting biomass into usable forms for energy or for chemical production. The first route is the biochemical approach of breaking down the cellulosic biomass into simple sugars (hydrolysis — or adding hydrogen atoms) and the subsequent fermentation of those sugars to produce ethanol (Fig. 1). Hydrolysis of biomass can be achieved either biochemically (enzymes) or microbiologically. Microbes (e.g. bacteria, yeast) ferment simple sugars to ethanol that is refined/enriched by distillation or membrane separation.

The second route is thermochemical conversion, which involves the breakdown of cellulosic biomass under heat and pressure to produce various combustion products (Fig. 1). This process involves pyrolysis of biomass that generates different proportions of gaseous (syngas), liquid (bio-oils), and solid (biochar) products based on the operating conditions. The syngas stream can be catalytically or microbially converted into biofuels. The bio-oil stream can be gasified and then converted into liquid fuels. The solid residue, termed *biochar* consists mainly of carbon and can be used as a soil amendment to enrich cropland and sequester carbon.

The third route is direct thermal conversion or the simple combustion of biomass to produce process heat (Fig. 1). Various methods of co-firing of biomass with pulverized coal, such as direct mixing and grinding of biomass with coal, direct biomass firing (cyclone burner), and separate biomass gasification and utilizing the combustible gas for process heat requirements. Biomass heating systems of medium and large scale burn densified biomass or wood chips and generate steam or process heat for turbines that produce electricity (biopower). Pelleted biomass or wood chips can also be used in domestic burners/stoves for direct heat space heating. The non-energy based pathway of biomass utilization is bioproducts formation. This pathway essentially involves several specialized processing stages that converts the raw biomass feedstock into several value added products and high-cost chemicals from biomass (e.g. fiber composites, degradable plastics, ferulic acid, succinic acid, glycerol).

Perennial forage crops for biomass

There is keen debate about the wisdom of growing bioenergy crops on land used for food production. Some suggest that bioenergy crops should be relegated to marginal land or land not used for human food production. Some perennial grasses, such as switchgrass, are relatively productive on marginal land that is not used for food production. High-yielding perennial forages, especially some tall grasses, offer many advantages as second-generation bioenergy crops including long-term persistence, low input requirements, potential to store carbon in the soil, and a favorable energy balance. Forages that have been studied for biomass production include switchgrass, Miscanthus, reed canarygrass and alfalfa.

Switchgrass, the most studied perennial grass for bioenergy in the U.S., is a warm-season perennial grass native to North America. It can persist and produce well on marginal

Table 1. Biomass yields from several switchgrass cultivars in the northern U.S. and Canada. Switchgrass was harvested once, typically in autumn and supplied with 50 -150 kg N/ha (45-135 lb N/ac). (For T/ac multiply by 0.45).

Cultivar	North Dakota[1]	South Dakota[2]	Wisconsin[2]	Iowa[3]	Ontario[4]	Quebec[5]
	t/ ha					
Cave-in-Rock	4.9	3.8	14.3	9.3	11.4	12.2
Dacotah	5.4	2.9	7.4			
Forestburg		3.9	9.4	6.9		
Shawnee	5.6	5.1	11.4	8.8		
Sunburst	7.4	4.6	11.5	6.8	9.9	10.6
Trailblazer	6.9	4.6	11.0	7.9		
Pathfinder					10.8	11.5

[1]Berdahl et al. 2005. *Agronomy Journal* 97:549-555.
[2]Casler et al., 2007. *Crop Science* 47:2249-2259.
[3]Lemus et al. 2002. *Biomass and Bioenergy* 23:433-442.
[4]Madakadze et al. 1999. *Agronomy Journal* 91:696-701.
[5]Jannasch et al. 2001. Resource efficient agricultural production (REAP)—Canada, Ste. Anne de Bellvue, Quebec.

and erosive land, and it has relatively low water and nutrient requirements. Switchgrass traditionally has been used for hay or grazing and in resource conservation programs. There are many varieties adapted to a wide range of sites and new varieties have been developed specifically for biomass feedstock production (Table 1). Switchgrass varieties are grouped into upland and lowland ecotypes. The upland ecotypes are best adapted to the dry, cool conditions of the northern Great Plains of the U.S. and the prairie provinces of Canada. Upland varieties include Cave-in-Rock, Sunburst, and Trailblazer, which are often grown for hay and grazing. Lowland ecotypes grow taller, have coarser stems, and are adapted to wetter conditions. Lowland varieties include Alamo and Kanlow. Switchgrass biomass yields have ranged from 3–14 t/ha (1.4-6.3 T/ac) in the northern U.S. and Canada. Switchgrass can accumulate greater amounts of soil organic carbon than annual crops (Fig. 2).

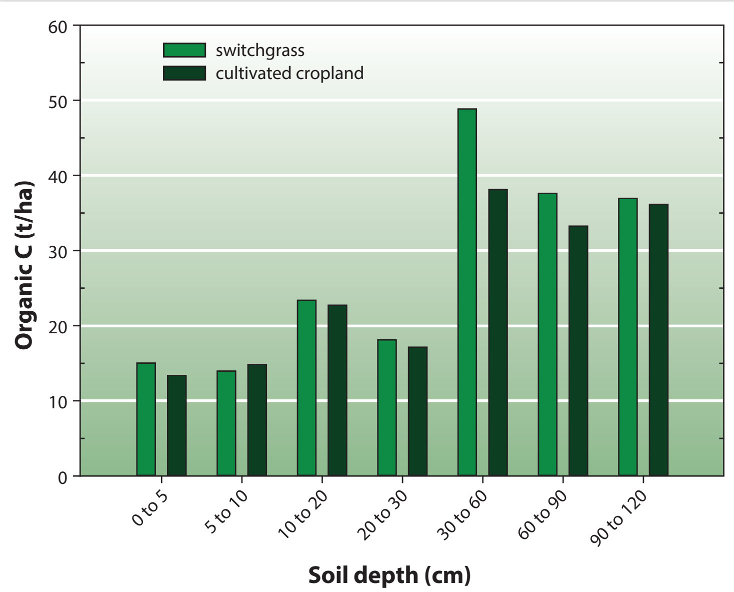

Figure 2. Soil organic carbon at different soil depths under switchgrass or cultivated cropland. (Mean of 42 sites in Minnesota, North Dakota, and South Dakota). Figure courtesy of Mark Liebig, USDA-ARS Northern Great Plains Research Laboratory, Mandan, ND. Liebig et al. (1 in = 2.54 cm) (for T/ac multiply by 0.45).

Insect pests and diseases have not been a large problem in switchgrass grown for hay or grazing. Recent close scrutiny has identified potential pests including a fungal smut, parasitic nematodes, anthracnose, and stem-boring caterpillars. These pests and pathogens may become more prevalent and require control measures if switchgrass (or any bioenergy crop) acreage increases dramatically.

Miscanthus, a tall warm-season grass native to Asia, has also captured much attention in the U.S. as a high-yielding perennial grass suitable for biomass production. There are related Miscanthus species used for ornamental grasses (e.g. *Miscanthus sinensis*); however, the high-yielding type of Miscanthus (*Miscanthus x giganteus*) used for biomass is a sterile triploid, and must be propagated and established from rhizome pieces. There are no commercial varieties of the triploid Miscanthus available and cost-effective planting methods have not yet been developed. Miscanthus has not been researched extensively as a bioenergy crop in North America and more information is needed on its range of

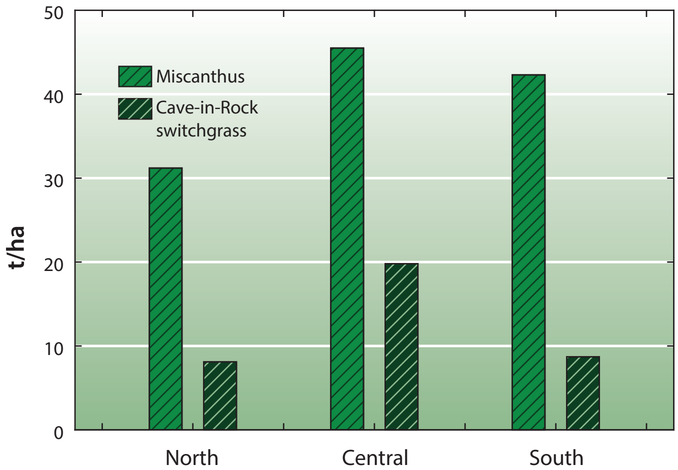

Figure 3. Biomass yields of Miscanthus and Cave-in-Rock switchgrass at three sites in Illinois. Adapted from: Heaton et al. 2008.

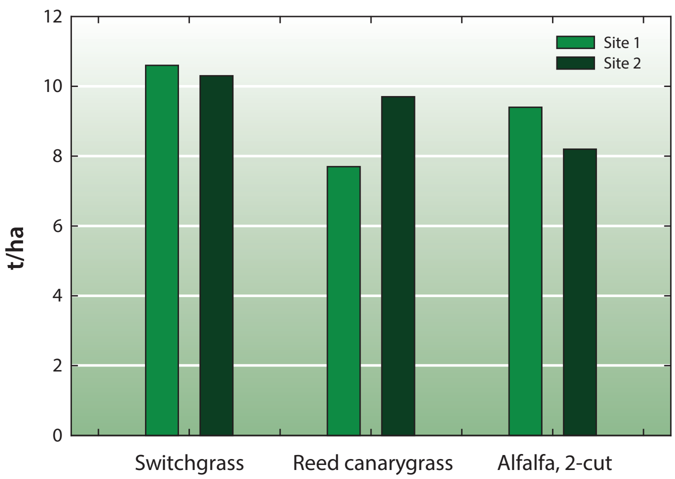

Figure 4. Yield of switchgrass, reed canarygrass, and alfalfa managed as bioenergy crops at two sites in Iowa. Switchgrass and reed canarygrass received 140 kg N/ha (125 lb/ac). Alfalfa received no nitrogen fertilizer. Adapted from: Hallam et al. 2001.

(for T/ac multiply by 0.45)

adaptation, yield, and persistence in different environments. In Europe, Miscanthus delivered very high yields (up to 40 t/ha or 18 T/ac) in southern Europe. Its productivity has been confirmed in central USA with yields of up to 45 t/ha (20 T/ac) in Illinois (Fig. 3).

Reed canarygrass also has been studied as a bioenergy crop in Europe and North America (Fig. 4). Reed canarygrass is adapted to temperate areas and does well on wet soils. The latter characteristic concerns some groups in North America because of the potential for reed canarygrass to invade native wetlands.

Several other grasses have been evaluated as potential biomass energy crops in western Canada (Table 2). Research at seven locations from Brandon, Manitoba to Lethbridge, Alberta compared several cool- and warm-season native grasses for biomass yields. The cool-season grasses yielded more biomass than warm-season grasses at the seven locations. Among the warm-season grasses, switchgrass and big bluestem produced the most biomass at the southern locations (Brandon and Lethbridge); none performed well at the two northern locations, Melfort and Vegreville, which are apparently outside the range of adaptation for these grasses.

Alfalfa has been touted as "dual use", for bioenergy and high quality animal feed. The concept calls for separation of alfalfa biomass into leaves for use as high-protein animal feed and stems for use as combustible biomass. The envisioned production system in the upper Midwest of the USA includes only two harvests per year to optimize economics, yield of stem and leaf, and wildlife habitat. Dual-use alfalfa could be a key component of bioenergy crop rotations with corn or other annuals, providing N for subsequent annual crops and organic matter for the soil.

Currently, there is no large scale demand or production of perennial crops for bioenergy. In the future, however, some farmers will need to make some strategic decisions regarding whether or not to grow perennial crops for bioenergy. Economic considerations will certainly drive that decision but other considerations, such as flexibility to grow other crops in rotation or to manage the perennial crop (e.g. switchgrass) as a forage crop to take advantage of other markets, will affect decisions as well. The option to use a perennial forage for both cattle forage and biomass could offer an attractive incentive for farmers in the Great Plains region of North America, which has a large inventory of beef cattle. Flexibility in its use could also provide an incentive to adopt perennial bioenergy crop production as a new enterprise.

Strategic planning also includes considerations such as soil and previous crop for site selection. Planning for establishment should begin one or more years in advance so that soil deficiencies and weed populations can be managed efficiently. Other important considerations are flexibility to respond to markets or climate with alternative crop choices, and production risks. Risk can be managed by contracting with the conversion facility and participation in government incentive programs and crop insurance. Risk management also applies to harvest decisions, whether managing to obtain forage for livestock early and biomass later, or a single fall harvest to maximize yield, or to risk yield loss by allowing stands to remain in the field overwinter to reduce mineral and water concentration for efficient harvest, storage, and conservation.

Management for bioenergy cropping

Most of the existing technology, machinery and infrastructure to establish, harvest and store forage should be adaptable to bioenergy crops. New technologies, however, will likely emerge as demand and production of biomass increases.

Table 2. Biomass yields (3-4 yr means) of 10 grasses at 7 locations in western Canada. Grasses were harvested once in September or October. (Adapted from Jefferson et al. 2002). (For T/ac multiply by 0.45).

Species	Entry	Brandon *Clay soil*	Brandon *Sandy soil*	Lethbridge	Melfort	Swift Current *Dryland*	Swift Current *Irrigated*	Vegreville
COOL-SEASON					*t/ ha*			
Thickspike wheatgrass	*Critana*	7.2	1.2	6.7	2.7	2.7	4.0	1.0
Green needlegrass	*Lodorm*	4.8	1.6	7.5	2.1	2.0	5.3	0.5
Mammoth wildrye	*ND-691*	10.5	2.4	15.8	3.0	2.2	6.6	1.5
Western wheatgrass	*Rodan*	6.9	2.0	7.7	3.3	2.2	5.2	1.0
WARM-SEASON					*t/ ha*			
Big bluestem	*Bison*	6.2	1.6	5.5	0.1	1.1	3.0	0
Switchgrass	*Dacotah*	6.5	1.7	7.0	0.1	1.0	4.3	0
Prairie sandreed	*Goshen*	0	1.8	9.5	0.2	1.1	2.4	0
Sideoats grama	*Killdeer*	3.7	1.1	3.4	0.5	0.2	0.4	0
Little bluestem	*Badlands*	5.7	1.5	3.5	0.1	0.4	0.2	
Indian grass	*Tomahawk*	4.8	0.1	4.7	-	0.1	0.2	0

Perennial crops grown for forage or bioenergy share some commonalities in management; however, of particular interest in bioenergy crop production are: (i) rapid establishment to generate harvestable biomass in the seeding year, (ii) highly efficient management of soil and fertilizer N to minimize external energy inputs, and (iii) harvest management to maximize yields of cellulosic biomass per land area.

Realizing economic yields of biomass during the seeding year requires rapid establishment of a dense stand of plants and enough time to accumulate biomass. This is especially critical if perennial crops are to be used in rotations with annual crops. Weed control is the principal limitation to achieving economic stands during establishment. Strategic management in the year before perennial crop establishment, including selecting a compatible preceding crop and the appropriate use of herbicides, can reduce weed pressure on the establishing stand.

Nitrogen fertilizer is energy intensive and its use on perennial grasses must be optimized to maintain a favorable energy balance taking into account the entire 'life cycle' of bioenergy production. Using legumes in crop rotations can reduce N fertilizer use. Nitrogen cycling mechanisms in some perennial crops can aid efficient N management. In warm-season grasses and alfalfa for example, N moves from the shoots to the plant crown or roots in autumn, which aids overwintering. In spring, the N is remobilized from the crown and roots back up to the shoots during regrowth. Switchgrass can be productive on low fertility soils; however, judicious use of P, K, and N fertilizers can greatly increase yields. Nitrogen fertilizer is not recommended at establishment because of increased weed competition but established stands require 50 to 150 kg N / ha (45-135 lb N/ac) depending on soils and climate.

Harvest management of bioenergy crops focuses on yield and persistence. In the alfalfa dual-use concept, the proposed management requires only two harvests, whereas hay management involves several harvests at bud to early flower stages to optimize yield, nutritive value and persistence.

Harvest management for switchgrass focuses on a single autumn harvest in several regions of the USA and Canada. Another option may be to delay harvest until late winter or early spring to reduce concentrations of mineral elements and moisture, which interfere with the combustion process. Delaying harvest, however, can substantially reduce yields.

Sustainable bioenergy production offers an exciting future alternative use of forages although current fossil fuel prices limit the competitiveness of renewable energy from biomass, without significant government subsidies. However, valuing additional ecosystem services provided by infrequently harvested perennial crops, such as soil carbon sequestration, reduced erosion, offset greenhouse gas emissions and wildlife habitat could alter the competitive balance.

References available online at www.farmwest.com

Matt A. Sanderson USDA-ARS Northern Great Plains Research Laboratory, Mandan, ND, USA | matt.sanderson@ars.usda.gov

Igathinathane Cannayen Agricultural and Biosystems Engineering, North Dakota State University, ND, USA