Optimizing Harvest Logistics Of Perennial Grasses Used For Biofuel

Switchgrass Background

Switchgrass (Panicum virgatum) is a warm season perennial grass native to the tallgrass prairie regions of the United States. In 1991 after a screening process, switchgrass was identified by both USDA and USDOE as a leading energy crop for electric generation, heating and as a feedstock for biofuels. It was selected because of its potential for broad distribution, ease of propagation, perennial growth habit, high yield potential, low requirements for agricultural inputs, compatibility with conventional farming practices and its excellent conservation attributes (Kszos et al., 2000). It is broadly adapted to a wide range of heat and cold and is suitable for use on marginal, droughty and highly erodible soils. As a perennial, switchgrass only needs to be established once, can be harvested annually, and requires reestablishment about every ten years. In terms of water quality, since tillage is only required in the establishment year soil erosion was reduced by 95% and pesticide use by 90% in switchgrass fields relative to annual crops like corn and soybean (Hohenstein and Wright, 1994). Additionally, switchgrass sequesters about 1 ton of soil organic carbon per acre each year (Follett et al., 2012; Casler and Boe, 2003). Research has also shown that displacing annual crops with native perennial grasses increases the nesting habitat for migratory birds and can help restore natural ecosystem functions in worked landscapes (Paine et al., 1996; Cook and Beyea, 1996).

Cenusa Researchers: Optimizing Harvest Of Perennial Grasses For Biofuel

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Kevin Shinners is a Professor of Agricultural Engineering at the University of Wisconsin. His role in the CenUSA project is to develop new systems to reduce the delivered cost of harvesting, handling, storage and transporting perennial grasses used for biofuels. His research focuses on what steps a producer can take to: reduce costs of harvesting feedstock, speed drying and reduce weather related losses, size-reduce material to increase transport density while potentially eliminating some downstream processing, and strategically placing bales during harvest to reduce aggregation costs. *Pamela Porter* is Outreach Specialist for the University of Wisconsin. She assists CenUSA in developing science based materials for Extension educators and the agricultural and horticultural industry.

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Cenusa bioenergy, a USDA-funded research initiative, is investigating the creation of a sustainable Midwestern biofuels system.

Research Partners

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Harvesting Background
An important goal of switchgrass grown as an energy crop (vs. a forage fed to animals) is to maximize yield. In the Midwest it is recommended that switchgrass be harvested once per year, typically in the fall after a killing frost. Perennial crops like switchgrass translocate nutrients (particularly N) from their leaves to their roots in the early fall aiding winter survival and reducing fertilizer requirements for next year's growth (Parrish et al., 1996; Vogel et al., 2002). Delaying harvest until after frost has also been shown to lower ash content, an important consideration for any thermal conversion process. Leaves are considerably higher than stems in ash content and delayed harvests have shown an increase in stem to leaf ratios (McLaughlin et al., 1996).

Figure 1: Adjust cutterbar gauge shoes so that stubble height is 4 to 6 in. to help trap snow and improve winter survival. Photo: Pamela Porter

Switchgrass can be harvested as dry hay with conventional equipment and stored in round or large square bales or it can be harvested with a forage harvester and stored in a bunk or bag silo. Each approach has positive and negative attributes. It is possible to store round bales outdoors, but losses will be great and the outer layer can be quite weathered (Shinners et al., 2010). Bale moisture also tends to be highly variable depending on weather conditions preceding removal. Large square bales should be stored under cover because they do not shed rainfall. In terms of transportation to the biorefinery, large square bales more completely fill the volume of a trailer than round bales and can maximize payload for transport to the biorefinery (Mitchell et al., 2008).

Figure 2: Adjust the tilt angle of the cutterbar more toward the horizontal to reduce cutterbar wear and reduce risk of damaging plant crowns. Photo: Pamela Porter

Although logistic systems for perennial grasses have focused on field drying followed by packaging in bales, there are issues with this approach. Dry bale systems are costly in terms of labor, timeliness, weather related losses, energy inputs, and storage losses. Another approach would be to harvest the grasses with a forage harvester so that size-reduction occurs at the instant of harvest, possibly eliminating some downstream processing requirements. Storing chopped grasses in a bunker or in silo bags may be less expensive, reduce labor needs and allow switchgrass to be harvested at higher moisture levels. Although harvesting by chopping provides a size-reduced feedstock, the material has very low bulk-density which challenges the economics of storage and especially transportation to the biorefinery.

Cutting High Yield Grasses
Switchgrass is a tall (> 6 ft.) prairie grass being bred to maximize yield. Traditional forage harvesting equipment can be used to harvest these crops, but machine performance will be different than typically experienced with forage crops. For instance, ground speed will be reduced because of high throughputs, so field productivity will be less. Disk cutterbar mowers are the only logical choice for harvesting high yielding switchgrass as use of sickle cutterbar mowers will produce very low productivity (Mitchell et al., 2012). Mowing equipment should be adjusted differently for high yielding biomass crops. It is recommended that switchgrass be cut higher (4 in. stubble height) than traditional forages to allow for trapping snow and aiding winter survival (Withers, 2009). Switchgrass stubble can be quite stiff and tire damage has been reported, so cutting higher can reduce this

problem, although yields will suffer. Set the cutting height by adjusting the gauge shoes to an upper position (Fig. 1). Tilting the cutterbar toward the horizontal (Fig. 2) will help reduce cutterbar wear and reduce chances of damaging the plant crown.

A seeding-year switchgrass stand in eastern Nebraska. This field produced 3.4 tons of switchgrass per acre after frost in the seeding year. Photo: Rob Mitchell

Switchgrass Drying Rate

Switchgrass yields are great and high yields usually means slower drying rate with traditional forage crops like alfalfa. However, research has shown that switchgrass actually dries more quickly than forage crops (Shinners et al., 2010). Reasons for this include lower initial moisture at cutting, stiff stems that produce tall, well-formed swaths that promote air movement, and large leaf surface area. Nonetheless, ambient temperatures will be low and daylight length short when switchgrass is harvested after dormancy, conditions that will challenge crop drying. The harvest window will be short between dormancy and snowfall, so quickly field drying when weather conditions are favorable will be important.

Traditional hay cutting and conditioning equipment was designed with alfalfa harvest in mind. But switchgrass has a thick, waxy stem that is difficult to condition for faster drying. Mower-conditioners are designed to be fairly gentle on the crop in order to maintain the nutritious and valuable leaves. Since switchgrass leaves have less tendency to be removed by conditioning than alfalfa leaves, more aggressive conditioning can be considered. Shinners is researching methods that can speed the drying of switchgrass by "intensive conditioning". Intensive conditioning has two components: hard crushing the stem between two rolls with very small clearance accompanied by "shredding" to disrupt the waxy epidermis of the stem. Shredding the stem is accomplished by passing the crop through rolls with differential speed. Wide-swath drying involves a post-cutting tedding operation that distributes the crop across the full cut-width instead of placing the crop in more traditional swaths that may only cover 50% of the cut-width. Although not consistent across all studies, intensive conditioning generally was more effective than wide-swath drying at improving switchgrass drying rate. The combination of intensive conditioning and wide-swath drying consistently resulted in the greatest drying rate. Future work will concentrate on machine configurations that can produce simultaneous intensive conditioning and full-width swaths at the time of cutting so that no additional field operations are required.

Improving Bale Density

Because of its thick and relatively tough stem, switchgrass resists compression in the baler. Previous research has shown that densities (dry basis) of round and large square switchgrass bales are 10-11 lbs/ft^3, which is 25 to 33% less than bale densities of typical forage crops like alfalfa or cool-season grasses (Mitchell et al., 2012). Shinners and his team are investigating ways to reduce the size of the material harvested to increase the density of switchgrass bales. Increasing bale density can reduce handling, transportation and storage costs. Increasing the bale density means truck weight limits can be maximized. To achieve this goal, Shinners is evaluating a "pre-cutter" a style of round baler commonly used in Europe. The pre-cutter is a slicing mechanism between the balers pick-up and bale chamber. It can theoretically slice material very fine and make the material easier to pack more tightly into the bale. Initial research has shown that pre-cutters can increase bale density by as much as 10%. However, bale densities are still not great enough to insure weight limited transport, so additional research is required to meet this goal.

Bale Handling And Aggregation

When biomass is packaged in bales, the bales typically are distributed in line with the original windrows but randomly located throughout the field. Collecting bales after harvest takes considerable time and equipment, adding to the delivered cost of the feedstock. Additionally, some bale handling schemes require considerable traffic across the field, resulting in undesirable soil compaction and plant damage. CenUSA researcher Shinners is investigating strategic bale placement schemes as a means to improve bale handling logistics. Time and motion studies for various bale placement and handling strategies have been conducted. Handling schemes have included one- and two-person bale retrieval with traditional tractor loaders; single versus multiple locations of the bale hauling trailer; and use of specialized bale moving machines. Overall, strategic bale placement has reduced time to load bales by 38% and total travel distance in the field by 40%. Although strategic bale handling did reduce total fuel required to handle bales, the specific fuel required to handle bales was small compared to that required for baling.

Figure 3: Harvesting dry switchgrass with a forage harvest to achieve conversion ready size-reduction in a single-operation reducing the number of downstream processes needed. Photo: Kevin Shinners

Energy Requirements Of Harvest And Processing

The cost of size-reducing biomass prior to conversion to biofuels or bioproducts represents a significant fraction of the total feedstock costs. To accurately estimate the delivered cost of perennial grass biomass, it is important to quantify the energy expended to harvest and process this feedstock. CenUSA researcher Shinners and his team have quantified the energy required to size-reduce biomass either at the time of harvest or post-storage. Three size-reduction systems were used: round baler with pre-cutter; forage harvester; and tub grinder. Using a pre-cutter on a baler increased bale density by 0 to 10% and increased specific fuel consumption by 10% to 23% with an average of 17%. A wide particle-size distribution resulted from use of the baler pre-cutter. Size-reduction by chopping with a forage harvester (Fig. 3) or by tub-grinding produced similar particle-size which was much smaller than with the baler pre-cutter. However, the combination of baling followed by post-storage tub grinding required more than twice the specific energy compared to chopping with a forage harvester. Although harvesting by chopping provides a size-reduced feedstock, the material has very low bulk-density which challenges the economics of storage and especially transport. Shinners and his team are working on ways to store the chopped feedstock in high-density “modules” and on systems to maintain the as-stored density during transport to eliminate the need for re-densification and reduce transport costs.

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