Giant Miscanthus

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Figure 1. Emily Heaton next to a stand of Giant Miscanthus on Caveny Farm, Monticello, IL. Each mark on the post = 1 foot. Photo Credit: John Caveny

This document is intended to provide general information on the biomass crop, Giant Miscanthus, with particular focus on agronomic potential and management.

Abstract

Giant Miscanthus (*Miscanthus* x *giganteus*) is a large warm season Asian grass, and a new leading biomass crop in the US. Experience in Europe suggests Giant Miscanthus will be productive over a wide geographic range in temperate regions, including marginal land, but is not appropriate for arid regions. Small trials in the Midwestern US indicate Giant Miscanthus can yield >2x more biomass than traditional switchgrass varieties. Fertility requirements need further investigation, but appear minimal if the crop is allowed to complete senescence and nutrient translocation before the annual harvest. Weed control is essential during establishment (1-3 years), then typically not required again. Stands are expected to last 15-20 years, depending on management. Recently established public and private trials around the US are supporting a wave of research and commercial development. Seeded varieties of Miscanthus are being developed, but closely scrutinized for invasive potential. If Giant Miscanthus can achieve the same yields at field scale that have been realized in research plots, enough biomass could be produced to meet US renewable commitments on only the land area currently devoted to corn grain ethanol.

Introduction - What is Giant Miscanthus?

Giant Miscanthus (*Miscanthus* x *giganteus* Greef et Deu.) is a perennial, warm-season Asian grass with the C_4 photosynthetic pathway. *Miscanthus* species have been used for forage and thatching in Japan for thousands of years, managed through burning and grazing in vast prairies similar to those managed by Native American tribes in the central US (Stewart *et al*., 2009). Giant Miscanthus was first collected in the 1930s as a horticultural specimen and is still planted in gardens because of its straight, tall stems and striking silver flowers (Fig. 1). In the search for ideal bioenergy crops following the oil crisis of the 1970s, evaluations to determine the biomass yield potential of Giant Miscanthus began across Europe.

Current and potential use as a biofuel

Giant Miscanthus has been studied in the European Union and is now used commercially there for bedding, heat, and electricity generation (Jones & Walsh, 2001). Most production currently occurs in

England, but also in Spain, Italy, Hungary, France and Germany. Recently, Japan and China have taken renewed interest in this native species and started multiple research and commercialization projects. In the US, research began at the University of Illinois at Urbana-Champaign in 2001 (Pyter *et al*., 2007) and has expanded rapidly to other US universities. Giant Miscanthus has been proposed for use in the US in combined heat and power generation, supplementing coal or on its own (Heaton *et al*., 2004, Khanna *et al*., 2008). It is also a leading candidate feedstock for cellulosic ethanol (DOE, 2006). Though it is widely touted for cellulosic ethanol, Giant Miscanthus has traits that likely make it better suited for thermochemical conversion processes over biological fermentation, at least under existing technology (Table 1).

Table 1. Traits of Giant Miscanthus that make it more (+) or less (-) amenable to conversion to biofuel.

Trait	Biological Conversion	Thermochemical Conversion
Low moisture at harvest (10-25%)	+/-	+
Low free sugar content	-	+
Low nitrogen content	-	+
High lignin content	-	+

The main feature distinguishing Giant Miscanthus from other biomass crops is its high lignocellulose yields. In the US, Giant Miscanthus can yield more annual biomass than any other major biomass crop save *Saccharum* spp. (sugarcane, energycane), and has a much broader growing range (Fig. 2). In small trials in Illinois, Giant Miscanthus yielded more than in European trials, and 2-4 fold more than native switchgrass (Fig. 6) (Heaton *et al*., 2008a). At average yields seen in Illinois trials, Giant Miscanthus has the potential to supply all the advanced biofuel required under the Energy Independence and Security Act (2007) using only the same land area currently devoted to producing corn grain ethanol. This means that Giant Miscanthus could meet biofuel goals without bringing new land into production or displacing food supply (Table 2).

Table 2. Biomass production, potential ethanol production, and land area needed for different potential bioenergy systems to reach the 35 billion gallon US renewable fuel goal (adapted from Heaton *et al*., (2008)).

Feedstock	Harvestable Biomass (Mg/ha)	Ethanol (gal/ha)[4]	Million Ha needed for 35 billion gallons of ethanol	% 2006 harvested US cropland[1]
Corn grain[1]	10.2	1127	31.0	24.4
Corn stover[2]	7.4	741	47.2	37.2
Corn Total	17.6	1868	18.7	14.8
Switchgrass	10.4	1040	33.7	26.5
Miscanthus	29.6	2960	11.8	9.3

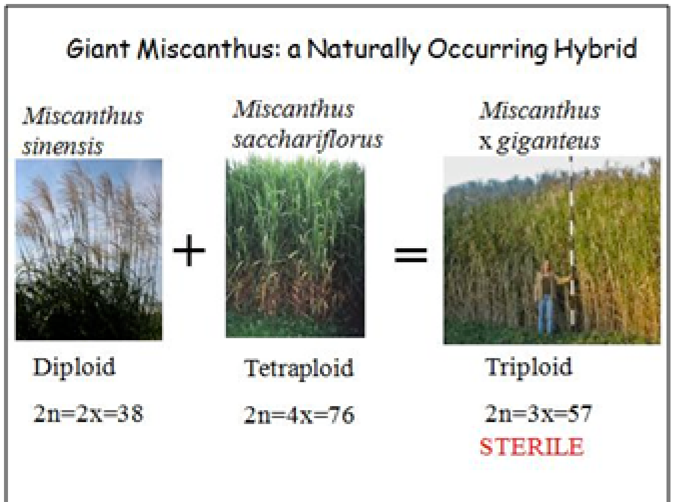

Figure 3. Representation of the hybrid origins of Giant Miscanthus (*M.* x *giganteus*), a naturally occurring hybrid grass first collected in Asia for use as an ornamental plant, and more recently for bioenergy.

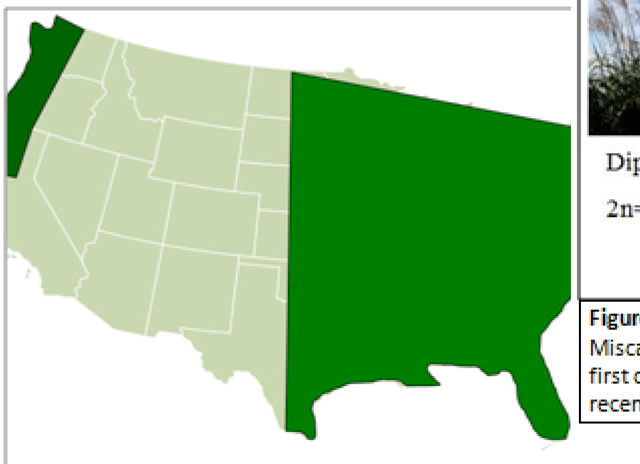

Figure 2. Theoretical growing range of Giant Miscanthus in the US. Giant Miscanthus is best suited for areas with at least 30 inches of rain per year, with better results as rainfall increases. Giant Miscanthus can tolerate wet soils and dry matter yield is directly correlated to seasonal precipitation.

[1](USDA-NASS, [2](Perlack et al., 2005), [3](Tilman et al., 2006), [4](DOE, 2006)

Biology and adaptation

Giant Miscanthus is a cross between *M. sacchariflorus*, a tetraploid species, and *M. sinensis*, a diploid species (Hodkinson *et al*., 2002). When crossed, they create the sterile triploid hybrid *M.* x *giganteus* (Fig. 3). *M. sacchariflorus* is characterized by fast-growing rhizomes and high productivity in warm, wet areas. *M. sinensis* relies primarily on seed for reproduction, and is found in montane environments that frequently have cold winters. The progeny of this cross, the hybrid Giant Miscanthus, can be thought of as "the mule of the plant world" – that is, it is sterile and bigger than either parent. Further, it inherited good cold tolerance and is currently the most productive crop known for cool, temperate regions of the world (Long, 1999). Giant Miscanthus is a close relative of sugarcane, but has low concentrations of sucrose, and *Miscanthus* spp. have been used to breed disease resistance and cold tolerance into sugarcane varieties. Moreover, there is a high degree of genetic similarity between the genera, suggesting genomic advances in sugarcane could also be used to improve *Miscanthus* (Amalraj & Balasundaram, 2006, Heaton *et al*., 2008b, Jensen *et al*., 2008).

Production and Agronomic Information

Field preparation

Best sited on well-drained soils, Giant Miscanthus also tolerates heavy soils and periodic flooding. When grown on marginal sites, as with most crops, yields are reduced, but still considered high compared to other perennial grasses. Best yields of Giant Miscanthus are likely to occur on ground suitable for annual row crops.

We recommend planting into a clean field following Roundup Ready™ soybeans to clear out the weed seed bank and avoid a heavy layer of crop residue. A fall cover crop of small grains may be used to protect the soil overwinter and provide weed suppression in the spring. The cover crop should be killed prior to planting Giant Miscanthus in the spring. A burn-down herbicide application may also be necessary to control spring weeds before planting. The whole field may be tilled prior to planting, or to better protect the soil and prevent weeds, tilled only in strips wide enough for planting (this will depend on planting equipment). Soil should be finely tilled to a depth of at least 15 cm.

Figure 4. A) Greenhouse grown "plug" of *M.* x *giganteus*. **B)** Field dug *M.* x *giganteus* rhizome. **C)** Field trial of *M.* x *giganteus* established (2008) with companion crops on the ISU farm in a split-plot design (main plot= companion crop, sub-plot = plug or rhizome propagule, n=4).

Planting

Planting technology is one of the major limitations to Giant Miscanthus use in the US today, for two reasons: limited plant material and limited planting equipment.

First, finding quality plant material of *known genetic background* is difficult (see Production Challenges below). There are only a few purveyors of Giant Miscanthus in the US today. Verifying that the material sold is actually Giant Miscanthus is essential to ensure that the sterile triploid hybrid is used and not a fertile variety that could become an invasive liability.

Second, dedicated machinery for planting Giant Miscanthus is being developed, but is not currently available in the US. Giant Miscanthus can be planted from rhizomes dug straight from a mother field or from greenhouse-grown plants, called plugs (Fig. 4). Certain types of vegetable transplanters are appropriate for both rhizomes and plugs, but there are issues to consider with each. For example, the rhizomes must be cleaned and sized to fit through the transplanter before planting. If planting plugs, it is critical to apply water at planting to ensure good survival. Rhizomes should be planted 5-10 cm deep and well covered. Plugs should be planted with the root ball below the soil surface. Both can be planted anytime after the frost free date, typically by May 1 in the Midwestern US.

We recommend planting at conventional spacing for available equipment, with good success using 72 cm (30 inches) between and within the rows. It appears that equal spacing around the plant gives better growth than planting at a higher rate within the row as is done with many annual crops. This spacing will also make it easier to include field cultivation as a weed control option in the establishment year.

Pest control

Controlling weeds in new plantings of Giant Miscanthus is necessary to develop a quality establishment. In research trials, good weed prevention has been realized through pre-plant and pre-emerge applications of pendimethalin and atrazine, with re-application as needed to prevent growth of grasses and small seeded broadleaves. Typically, little to no herbicide is needed by the third year after planting. It is essential that perennial grass weeds not become established in a newly planted field. Quinclorac and alachlor have also been used to control post-emergent grass weeds with some success. Broadleaf weeds are easily controlled with 2,4-D. Because Giant Miscanthus is a new crop and on very limited acreage in the US, currently *no herbicides are specifically labeled for use*. Please refer to product labels for complete legal information.

At present, there are no commercial pests of Giant Miscanthus in the US or Europe. Given the clonal nature of the crop, any pest issues that do arise may become serious.

Fertility

The importance of fertilizer to increasing harvestable yield is still not clear. Although productivity is often higher on more fertile soils (Clifton-Brown *et al*., 2001) frequently higher yields are realized on poorer soils if other environmental conditions, such as temperature, are favorable (Heaton *et al*., 2008a). Numerous studies have investigated yield responses to nitrogen (N) fertilizer with varying results (Lewandowski *et al*., 2000), frequently showing no significant yield increase, even after several years of biomass removal (Christian *et al*., 2008). Yield increases have been most commonly seen on sandy soils under irrigation, e.g. (Cosentino *et al*., 2007), with responses less clear under water limitation. In Ireland, a stand growing on marginal land for 16 years showed a response to potassium fertilization, but not to N (Clifton-Brown *et al*., 2007) suggesting other nutrients may limit yield before nitrogen. The apparent N use efficiency of Giant Miscanthus is thought to result from effective internal cycling of the N, i.e., N taken up by the crop during active growth is translocated to the rhizomes during senescence, where it is stored then used again during the following year's growth (Heaton *et al*., 2009).

The wide variety of results from the limited number of studies done on Giant Miscanthus fertility have made best management recommendations difficult, with most authorities advising a regime modified from forage management. Currently, we recommend that soil be tested before planting and brought within the following parameters given in Table 3.

Table 3. Preliminary fertility requirements for Giant Miscanthus in the Midwest US.

Parameter	Recommended range
Soil pH	6-8
N	2.5-4 kg Mg^{-1}removed (5.5-9 lb/ton)
K	2.5-4 kg Mg^{-1} removed (5.5-9 lb/ton)
P	0.7 kg Mg^{-1} removed (1.5 lb/ton)

Harvest

Giant Miscanthus can be harvested with a variety of conventional hay or silage equipment (Fig. 5). To fully realize nutrient cycling during senescence (see Fertility, above) the crop should be allowed to fully dry down before harvest. The typical harvest window for Giant Miscanthus is after a killing frost and before the emergence of new shoots in the spring. Crop moisture in Illinois trials ranged from 50% in October to less than 10% by February (Heaton, 2006).

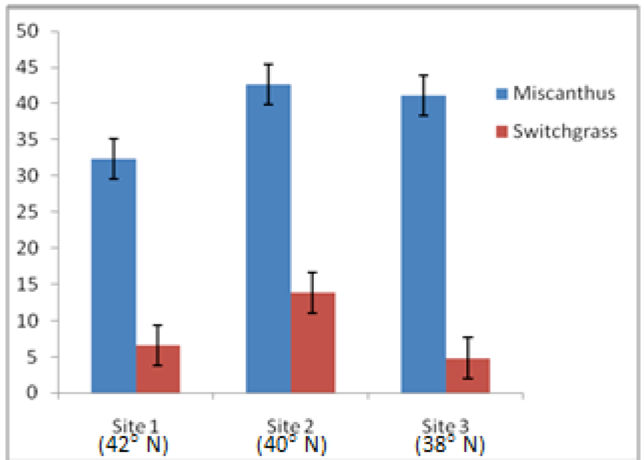

Figure 6. The average annual biomass yields of Giant Miscanthus and switchgrass harvested from 3 locations (latitude) in Illinois during 2004-2006 (adapted from Heaton *et al*, 2008).

The mineral content of harvested feedstock decreases with delayed harvest in both European (Lewandowski *et al*., 2003) and US experience as rain and snow leach minerals from standing biomass. This reduction in mineral concentrations generally increases feedstock quality for conversion to biofuel. However, it comes at a price; harvestable biomass can decrease 30-50% over the winter as leaves drop and stems break with wind and weather (Heaton *et al*., 2008a, Heaton *et al*., 2009).

Potential yields (tonnage and energy content)

There is currently little published information on Giant Miscanthus yields in the US. Tiller production and dry matter partitioning were examined in trials in Arkansas, and varied little between Giant Miscanthus and energy cane accessions (Burner *et al*., 2009). Similar measurements in Illinois showed Giant Miscanthus produced significantly fewer but larger tillers than switchgrass (*Panicum virgatum*)with increased tiller height and diameter contributing to greater biomass yields over switchgrass (Heaton *et al*., 2008a). Small plot trials of Giant Miscanthus have correlated well with modeled yield projections in Illinois (Fig. 6, 7), and suggest seasonal peak biomass production of 27-44 Mg ha^{-1}.

To validate yield potential across a wider geographic range, the same plot design used in the Illinois trials has now been replicated across several states in 2008 and 2009 as part of the US Dept. of Energy's Regional Feedstock Partnership (http://ncsungrant.sdstate.org/biomassFeedstockPartnership.cfm). Additionally, numerous universities now have trials evaluating Giant Miscanthus and thus, the availability of yield data is expected to increase dramatically in the next few years.

Figure 5. A variety of conventional hay forage equipment is suitable for Giant Miscanthus harvest. Photo credits: Emily Heaton and Carl Hart.

In the absence of widespread US observations, the European literature provides a good estimate of what may be expected from Giant Miscanthus under similar conditions. The considerable biomass data available from Europe suggests that Giant Miscanthus will yield from 10-40 Mg ha^{-1}, with higher yields in warmer, wetter areas with moderately heavy soils. Further, the literature suggests that Giant Miscanthus is productive at high latitudes, e.g. 52°N, or the equivalent of Hudson Bay (Beale *et al*., 1996). It remains to be seen if Giant Miscanthus can withstand the cold temperatures prevalent in North America at these latitudes compared to the European equivalents.

Production challenges

Propagation

Giant Miscanthus has been propagated for research trials by digging plants from a field then propagating them in a greenhouse (Fig. 4) or by directly transplanting rhizomes dug from existing field stands. Giant Miscanthus cannot be imported from Europe in any meaningful quantities due to current quarantine restrictions imposed by the USDA. Because Giant Miscanthus is a relative of sugarcane, it could conceivably harbor diseases that would threaten the US sugarcane industry. Imported rhizomes must be monitored in quarantine greenhouses for 3 years before release, a costly process that effectively eliminates importation.

Overwinter survival

A major bottleneck to Giant Miscanthus production in the upper Midwest is overwinter survival. Anecdotal evidence suggests that if a plant lives through the first winter, it is highly likely to survive subsequent winters. Cover during the winter also seems to effect survival: first year stands that were mowed in October experienced high mortality in Michigan and Wisconsin, compared to stands that were not mowed (Dennis Pennington and Chris Kucharik, *personal communication*).

Estimated production cost

The costs of Giant Miscanthus production are front loaded (Table 4). Depending on the source, planting material alone can cost \$1000-\$10,000 acre^{-1}. When considered over the productive lifetime of a stand, which is likely 15-20 years, the costs of production are less than annual row crops, leading to increased profitability, even without subsidy. Once established, Giant Miscanthus requires little maintenance, no annual re-planting, and only an annual harvest. Given the low-input nature of the crop, it is likely that custom operators will arise to handle Giant Miscanthus production ~~of~~ for interested land managers.

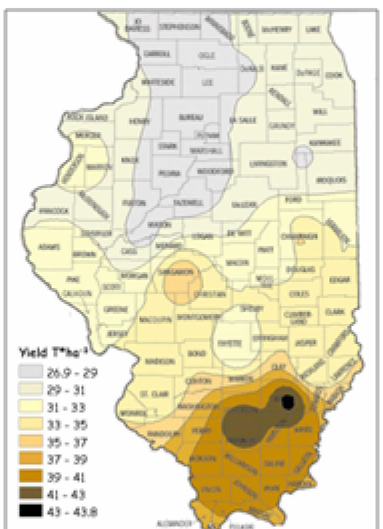

Figure 7. Projected peak dry matter yields of Giant Miscanthus in Illinois (adapted from Heaton *et al.*, (2004)).

Importantly, there are no actual field scale economic data yet available for Giant Miscanthus production in the US.

Environmental/sustainability issues

Is it (will it be) a weed?

Because Giant Miscanthus has 3 sets of chromosomes and an uneven chromosome number, the chromosomes do not divide evenly during meiosis, leading to non-viable gametes, and hence to sterile seed (Scally *et al*., 2001). This is advantageous because it limits the capacity of Giant Miscanthus to spread unintentionally from seed, but it significantly complicates planting of new fields (see Planting, above). In addition to lacking reproduction from seed, the rhizome structure of Giant Miscanthus spreads very slowly, thus minimizing vegetative spread. The oldest research stands in Europe were planted in the late 1980s and have only moved approximately 3 feet from their original location (Uffe Jorgensen, personal communication). Trials are currently underway in Illinois to evaluate risk of spread to and from agricultural lands.

The Path Forward

Table 4. Projected costs and return from *Miscanthus* x *giganteus* compared to a traditional corn and soybean rotation over 10 years in Champaign County, IL USA; 2003 prices.

Costs/acre:		
	Corn/Soy	Miscanthus
Seed	$203	$128
Others	$1748	$748
Land	$1198	$1198
TOTAL	**$3149**	**$2074**
Crop Income[1]	**$2670**	**$3004**
NET	**-$479**	**$930**

[1]Assumes 166 bu/ac and 2.50 $/bu corn; 52 bu/ac and 5.30 $/bu soy; 14 t/ac and 40.00 $/t Miscanthus (Dynegy $40; EU $69); and **no subsidies.** Heaton *et al*., (2004) Mitigation and Adaptation Strategies for Global Change, **9**, 433-451.

Summary

In summary, Giant Miscanthus is one of the most promising biomass crops in the US today. It is a cold-tolerant cousin of sugarcane, and capable of high biomass yields at cool temperatures. Further, it tolerates marginal lands and some flooding. It is ~~more~~ amenable to thermochemical conversion to biofuel ~~than~~ as well as biochemical conversion, with good potential for ~~the~~ direct combustion to heat and power as well as animal bedding industries. Giant Miscanthus is distinguished from other biomass crops by its high yields, particularly at cool temperatures, which can be more than double those typical of switchgrass. Giant Miscanthus shows an inconsistent response to fertilizer, and is generally characterized by low input requirements for production. These low inputs and consistently high yields make Giant Miscanthus potentially more profitable than~~t~~ corn/soy in the Midwest over the long term, despite the high cost of establishment given that the crop must be established vegetatively from rhizomes or plugs. Using high yielding biomass crops like Giant Miscanthus for fuel over food crops like corn may allow the US to achieve its biofuel mandates without competition between food and fuel.

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