Soil Fertility Recommendations: Nitrogen, Phosphorus, and Potassium Requirements of Miscanthus

Figure 1: *Miscanthus growing next to corn and sunflower. Photo credit: AGgrow Tech / Tribbett Farm*

Miscanthus x *giganteus* (hereafter referred to as miscanthus) is a perennial warm-season grass. Miscanthus is gaining popularity in the United States as a low-input bioenergy crop and as a poultry bedding source in Maryland and other states. Miscanthus could potentially be a viable crop on marginal lands, such as those affected by flooding, salt-intrusion, or intense deer pressure. Miscanthus is a sterile hybrid of two species, i.e., *Miscanthus sinensis* and *Miscanthus sacchariflorus* [1], and needs to be propagated by rhizome divisions [2]. Once miscanthus is established, it can reach a height of up to ~12 feet [3] (Figures 1 and 2) and maintain maximum biomass production for up to 15 years [4]. As a perennial rhizomatous grass, miscanthus can translocate nutrients to the rhizomes at the end of the growing season, resulting in lower fertilizer requirements the following season and reduced input costs [5].

Site Selection and Establishment Considerations for Miscanthus

When selecting a site for growing miscanthus, you should consider soil properties and water availability. Miscanthus shows a strong response to available water, which may be the most constraining factor in production [6]. Miscanthus may not perform well in areas with limited water availability [7]. Regions that receive at least 30 inches of annual rainfall are recommended for the most widespread "Illinois" type miscanthus clone [2]. Maryland and the northeastern United States, on average, receive more than 38 inches of rainfall in a year, so water limitation is not an issue in most soils. Once established, miscanthus is typically able to withstand dry periods and grow again the following year, although biomass yield can be negatively affected in drought years [3]. However, the root system of miscanthus becomes extensive as it establishes, reaching down as far as ~8 feet, allowing the crop to survive in soils with low nutrient availability [8, 9] and utilizing water present in the deep soil profile. In addition to resilience following drought, miscanthus may also be resistant to challenges associated with high water tables or root-restricting layers. Illinois trials of miscanthus on undrained soils of high-water tables or root-restricting layers provided comparable yields to those cited below [10; Emily Heaton, personal communication].

Miscanthus can grow in a wide variety of soils with an optimum pH between 5.5 and 7.5. This means that most soils in Maryland are suitable for miscanthus production. Miscanthus is typically harvested in winter or early spring (Figure 2), but may also be harvested in the fall or, in a two-cut system, late spring/early summer and again in the fall. Soils that are waterlogged during the planned harvest period are not ideal for growing miscanthus [3].

Figure 2: *Miscanthus in winter prior to harvest. Photo credit: Mr. Bud Malone*

Typical Yields of Miscanthus in the United States

Miscanthus does not reach its full yield potential until at least the third growing season in fertile soils or later seasons in poorer soils [11] (Figure 3). In North Carolina, yields range from 8 US tons (tons hereafter refers to US tons where 1 US ton = 0.91 metric ton) dry matter (DM) per acre on sandy, weathered (Paleudult) soils [12] to 15 tons DM per acre on more fertile, clayier (Hapludalf) soils [13]. In addition to yield

Figure 3: *First-year stand of miscanthus (5-6 feet tall). This stand was planted in early May 2019 and photo was taken late July 2019. Photo credit: Dr. Sarah Hirsh, UME.*

differences that may correspond to soil type, a speculative yield penalty has been suggested for Miscanthus above the northernmost latitude occurring in Maryland [14]. Yields within the range observed in North Carolina have been observed in Louisiana (8 tons DM per acre) [15], Illinois (10-15 tons DM per acre) [14] and Michigan (9 tons DM per acre) [16]. Peak harvestable aerial DM biomass occurs in late summer or early fall, resulting in a potential yield increase of up to 30% over winter harvest following crop senescence [10]. Two-cut harvest systems may not offer yield benefits over single-cut harvest systems [12].

Given the above experience, yields ranging from 8 to 15 tons DM per acre can be expected in Maryland. Once established, growers should maintain yield records to estimate future yield goals and optimize fertilizer application rates.

Literature Review of Nutrient Requirements of Miscanthus

In general, nutrient requirements of miscanthus are relatively low [17]; however, researchers have not determined the specific nutrient requirements for Maryland. Current literature has not sufficiently defined the nitrogen needs of miscanthus [18]. There are conflicting reports in the scientific literature on whether nitrogen fertilizer application increases yield. Some studies have indicated little or no yield response to nitrogen fertilizer application [3, 19, 20, 21], whereas others have shown a positive yield response [3, 7, 22, 23, 24, 25, 26].

Shield et al. [22] found that the application of 45 to 90 pounds of nitrogen per acre increased biomass yields in sandy soils with low organic matter and low nutrient retention capacity. Another study on similar soils in North Carolina found a yield increase at 120 pounds of nitrogen per acre compared to 60 pounds of nitrogen per acre in the fall harvest and two-cut systems [12]. Such sandy soils with low organic matter are found in coastal plain soils on the eastern shore of Maryland. Thus, it can be expected that there is a yield benefit associated with nitrogen fertilizer application in Maryland soils with low organic matter. Research also showed evidence of a nitrogen-fixing bacterium association with miscanthus, which means that miscanthus may be able to use fixed atmospheric nitrogen just as legumes do [27].

Researchers have not determined the pre-plant fertilizer needs for establishing miscanthus. In Maryland, pre-plant applications of phosphorus and potassium are based on soil test results, estimated crop needs in the establishment year, and estimated nutrient availability. Following the establishment year, nutrient requirements should be based on the amounts of nitrogen, phosphorus, and potassium the crop is expected to remove [17, 28]. However, nitrogen is not recommended in the first (establishment) and second growing season as the application will increase weed pressure with no justifiable yield benefit [3]. The limited published seasonal nutrient concentrations in miscanthus indicate that complete translocation of nutrients from the shoots to the rhizomes occurs in the fall for nitrogen and in winter for phosphorus and potassium [17]. Nutrient recommendations for maintenance of miscanthus are adjusted based on harvest time considerations.

Growers should consider their individual goals and the economics of miscanthus production when choosing fertilizer application rates and harvest timing. Winter harvest is recommended to maximize nutrient translocation and recycling in miscanthus, thereby decreasing input costs. Alternatively, fall harvest may be considered for soils testing high in phosphorus and potassium.

Nutrient Recommendations for Miscanthus Production in Maryland

The following two tables show nutrient recommendation for establishment (Table 1) and maintenance (Table 2) of miscanthus for Maryland soils.

In summary:

- Nitrogen application is recommended at 10 lb per ton of DM expected yield, beginning at year 3. Nitrogen is not recommended in the first and second growing seasons due to lower yield potential and increased weed pressure.
- Phosphorus application is recommended at 2.29 lb P_2O_5 per ton of DM expected yield. No phosphorus is recommended at soil test phosphorus levels above 100 FIV-P (Excessive category).
- Potassium application is recommended at 16.9 lb K_2O per ton of DM expected yield. No potassium is recommended at soil test potassium levels above 100 FIV-K (Excessive category).

Appendices 1 and 2 describe in detail how we determined these recommendations.

Table 1: Plant nutrient recommendations for the establishment of miscanthus (pounds/acre). Nutrients to be applied prior to planting, either by broadcasting or disking[1]

Nitrogen[2] (lb N/A)	Phosphorus (lb P_2O_5/A)				Potassium (lb K_2O/A)			
	Soil Test Phosphorus Category[3]				Soil Test Potassium Category[3]			
	Low[4]	Medium[4]	Optimum[4]	Excessive	Low[4]	Medium[4]	Optimum[4]	Excessive
0	65-90	20-65	0-20	0	80-105	50-80	0-50	0

[1]See Appendix 1 for detailed calculations. Note that 1 lb of P is equivalent to 2.29 lb of P_2O_5 and 1 lb of K is equivalent to 1.21 lb of K_2O.

[2]Nitrogen is not recommended in the first (establishment) growing season due to lower yields and increased weed pressure.

[3]Soil test phosphorus or potassium categories in Maryland are expressed as fertility Index Values (FIV), as follows: Low: FIV level of 0–25; Medium: FIV level of 26–50; Optimum: FIV level of 51–100; Excessive refers to FIV level above 100. Consult University of Maryland Extension publication SFM-4 (https://go.umd.edu/SFM-4) for converting lab analysis values to FIV.

[4]Where ranges of nutrients are indicated for phosphorus and potassium, the precise amount of plant nutrient required depends upon the numerical soil test index value for that nutrient.

Table 2: Plant nutrient recommendations for the maintenance of miscanthus (pounds/acre). Nutrients to be top-dressed annually[1]

Nitrogen[2] (lb N/A)	Phosphorus (lb P_2O_5/A)[3]				Potassium (lb K_2O/A)[4]			
	Soil Test Phosphorus Category[5]				Soil Test Potassium Category[5]			
	Low	Medium	Optimum[6]	Excessive	Low	Medium	Optimum[6]	Excessive
80	20	20	0-20	0	135	135	0-135	0

[1]See Appendix 2 for detailed calculations. Recommendations are for a yield goal of 8 tons DM/acre, but values will vary based on yield goal. Full yield potential is not reached until at least the third growing season. Recommendations for the second growing season should be based on approximately half of the maximum yield potential.

[2]Nitrogen is not recommended in the second growing season due to lower yields and increased weed pressure. In a two-cut harvest system (i.e., spring cutting and fall/winter cutting), increase nitrogen rate by 25%. Split nitrogen application is recommended. Apply 50% of the nitrogen recommendation in the spring before re-growth and apply the remaining 50% after the first cutting.

[3]Phosphorus recommendation assumes winter harvest. In a fall harvest system, increase phosphorus application rate by 75%. Note that 1 lb of P is equivalent to 2.29 lb of P_2O_5.

[4]Potassium recommendation assumes winter harvest. In a fall harvest system, increase potassium application rate by 25%. Note that 1 lb of K is equivalent to 1.21 lb of K_2O.

[5]Soil test phosphorus or potassium categories in Maryland are expressed as fertility Index Values (FIV), as follows: Low: FIV level of 0–25; Medium: FIV level of 26–50; Optimum: FIV level of 51–100; Excessive refers to FIV level above 100. Consult University of Maryland Extension publication SFM-4 (https://go.umd.edu/SFM-4) for converting lab analysis values to FIV.

[6]Where ranges of nutrients are indicated for phosphorus and potassium, the precise amount of plant nutrient required depends upon the numerical soil test index value for that nutrient.

Invasive Potential of Miscanthus

While perennial grasses are leading candidates as bioenergy crops, they are also recognized for their success as invasive species. Grasses can regenerate by both wind-dispersed seeds and rhizome fragmentation [29]. *M. x giganteus* (in contrast to its close relatives *M. sacchariflorus* and *M. sinensis*) is sterile and unable to produce viable seeds, limiting its invasive potential. A weed risk assessment conducted for miscanthus production in the United States gave miscanthus an “accept” rating, indicating “relatively minor risk of invasion” [30]. The private industry has developed at least one fertile (i.e. viable seed-producing) variety of *M. x giganteus* in efforts to reduce planting costs [31]. Fertile varieties are not currently recommended for production in Maryland due to the increased invasive potential.

Once established outside of production fields, miscanthus may be difficult to control. Despite the low risk of escape or spread, growers should follow best management practices (BMPs) focused on limiting unintentional spread via rhizome fragmentation. Recommended BMPs include, but are not limited to, establishment and maintenance of a 25-foot setback or border surrounding miscanthus stands (setback is not required when planting is adjacent to cropland or pasture actively managed by the same operator), covering or containing rhizomes during transportation, inspection and removal of plant residues from all equipment, and proper disposal of excess planting material. Refer to USDA-NRCS Technical Note No. 4, *Planting and Managing Giant Miscanthus as a Biomass Energy Crop* [28] for additional details on BMPs for preventing the unintentional spread of miscanthus.

APPENDIX 1:

Assumptions for calculating nutrient needs of Miscanthus at the establishment (year 1):

Yield Potential: As miscanthus yields do not reach full yield potential until the third growing season, the establishment recommendations for the first growing season are based on 3 tons of DM per acre yield potential in the establishment year.

Nutrient Removal: Cadoux et al. [17] conducted a comprehensive literature review of crop removal data for miscanthus and reported median (as opposed to average) values for nutrient removal. They determined that nitrogen crop removal was 10 lb of nitrogen per ton DM yield, phosphorus crop removal was 2.29 lb of P_2O_5 per ton DM yield, and potassium crop removal was 16.9 lb of K_2O per ton DM yield. We used these values of nutrient crop removal for calculating fertilizer recommendations for Maryland.

Phosphorus Use Efficiency: Ravella et al. [13] looked at varying fertilizer rates for miscanthus production, with 120 lb P_2O_5 per acre suggested as optimal phosphorus fertilizer application rate. The average yield at this rate in this study was 14.5 tons DM per acre. Using 2.29 lb P_2O_5 removed per ton of DM based on Cadoux et al. [17] and 14.5 tons of DM per acre in Ravella et al. [13], total phosphorus removal was 33.2 lb P_2O_5 per acre. Thus, of 120 lb P_2O_5 applied in this study, 33.2 lb of P_2O_5 was removed by miscanthus, resulting in phosphorus use efficiency (PUE) of approximately 28%. Crop recovery of applied phosphorus tends to be more efficient as you reach agronomic soil test critical values [32], and researchers estimate crops recover approximately 15 to 30% of applied phosphorus annually [33].

Recommendations:

Nitrogen: No nitrogen is recommended in the establishment year as miscanthus is being established and has minimal nitrogen needs, which are met by the soil pool via mineralization of organic matter.

Phosphorus: Based on Cadoux et al. [17], we know that 2.29 lb P_2O_5 is removed per ton of DM. Beale and Long [5] and Himken et al. [3] estimated the partitioning of phosphorus in the biomass and found that 38% is in the DM (harvested material), whereas 41.5% stays with the rhizomes and the remaining 20.5% returns to the soil. Using a known value of 2.29 lb P_2O_5 removal per ton of DM, we can estimate the amount that goes back to rhizome (2.5 lb P_2O_5) and the soil (1.2 lb P_2O_5).

Adding these three components (removal + rhizomes + soil) will give the total amount of P_2O_5 needed (6 lb) to produce 1 ton of DM during the establishment phase. Adjusting for yield (3 tons per acre in establishment year) and PUE (28%), we can calculate the phosphorus establishment rate as follows: 6 lb P_2O_5 per ton DM x 3 tons DM per acre x PUE at 28% = ~65 lb P_2O_5 per acre maximum recommendation in soils tested with medium (FIV-P range 26-50) levels of phosphorus. At low soil test phosphorus levels (FIV-P range 0-25), a slightly lower PUE (20%) is used to account for increased soil buffering capacity of phosphorus in acidic soils, resulting in a maximum application of 90 lb P_2O_5 per acre. At optimum soil test phosphorus levels (FIV-P = 50), 20 lb P_2O_5 per acre is recommended to match crop removal and maintain optimum levels. A linear decrease of phosphorus application is recommended as follows:

- Low category: 0 FIV-P soil level (90 lb P_2O_5 per acre) to 25 FIV-P soil level (65 lb P_2O_5 per acre).
- Medium category: 25 FIV-P soil level (65 lb P_2O_5 per acre) to 50 FIV-P soil level (20 lb P_2O_5 per acre).
- Optimum category: 50 FIV-P soil level (20 lb P_2O_5 per acre) to 100 FIV-P soil level (0 lb P_2O_5 per acre).
- Excessive category: No phosphorus is recommended for establishment in soils above 100 FIV-P.

Potassium: Based on Cadoux et al. [17], we know that 16.9 lb K_2O is removed per ton of DM. Beale and Long [5] and Himken et al [3] estimated the partitioning of potassium in the biomass and found that 47.5% is in the DM (harvested material), whereas 22.5% stays with the rhizomes and the remaining 30% returns to the soil. Using a known value of 16.9 lb K_2O removal per ton of DM, we can estimate the amount that goes back to rhizome (8 lb K_2O) and the soil (10.7 lb K_2O). Adding these three components (removal + rhizomes + soil) will give the total amount of K_2O needed (35.4 lb) to produce 1 ton of DM during the establishment phase. Adjusting for yield (3 tons per acre in establishment year) and potassium availability (100%), we can calculate the maximum potassium establishment rate as follows: 35.6 lb K_2O per ton x 3 tons DM per acre = 106.8 lb K_2O per acre (~105 lb) maximum recommendation in soils tested with low levels of potassium. A linear decrease of potassium application is recommended from soil in Low, Medium, and Optimum categories, ranging in 0 FIV-K soil level (105 lb K_2O per acre) to 100 FIV-K soil level (0 lb K_2O per acre). No potassium is recommended for the establishment at soil test levels above 100 FIV-K (Excessive category).

APPENDIX 2:

Assumptions for calculating nutrient needs of *Miscanthus* at the maintenance (year 2 onwards):

Yield Potential: Full yield potential of miscanthus is not reached until at least the third growing season. Yield potential in the second growing season is estimated to be half of the full yield potential achievable in year 3 onward.

Nutrient Removal: Cadoux et al. [17] conducted a comprehensive literature review of crop removal data for miscanthus and reported median (as opposed to average) values for nutrient removal. They determined that nitrogen crop removal was 10 pounds of nitrogen per ton of DM yield, phosphorus crop removal was 2.29 lb of P_2O_5 per ton of DM yield, and potassium crop removal was 16.9 lb of K_2O per ton of DM yield. We recommend using these replacement values of nutrient crop removal for applying fertilizers in Maryland in soils under miscanthus production.

Harvest Timing: Crop removal data and, therefore, maintenance recommendations assume a single annual winter harvest. Fall harvest will remove slightly higher phosphorus and potassium while a two-cut system, including a late spring/early summer harvest, will remove slightly higher nitrogen [17]. To account for this, fall harvest production systems should increase the recommended phosphorus application rate by 75% and the recommended potassium application rate by 25%. Two-cut systems that include a late spring/early summer harvest should increase the recommended nitrogen application rate by 25% and apply as a split application, with 50% applied in early spring before re-growth begins and the remaining 50% applied following the first cutting.

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Brian Kalmbach

Dr. Gurpal Toor

gstoor@umd.edu

Dr. David Ruppert

This publication, *Soil Fertility Recommendations: Nitrogen, Phosphorus, and Potassium Requirement of Miscanthus* (EB-443), is a part of a collection produced by the University of Maryland Extension within the College of Agriculture and Natural Resources.

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