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# Biomass yield, nitrogen response, and nutrient uptake of perennial bioenergy grasses in North Carolina

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ABSTRACT

Although perennial grasses show considerable potential as candidates for lignocellulosic bioenergy production, these crops exhibit considerable variation in regional adaptability and yield. Giant miscanthus (*Miscanthus* × *giganteus* Greef & Deuter), *Miscanthus sinensis* Anderss. 'Gracillimus' and MH2006, plume grass (*Saccharum arundinaceum* Retz.), ravenna grass (*Saccharum ravennae* (L.) L.), switchgrass (*Panicum virgatum* L. 'Alamo'), and giant reed (*Arundo donax* L.) field plots were established in 2008, treated with four nitrogen (N) fertilizer rates (0, 34, 67, 134 $kg\,ha^{-1}\,y^{-1}$), and harvested annually in winter from 2008 to 2011. Giant reed, 'Gracillimus', switchgrass, MH2006, giant miscanthus and ravenna grass at the Mountain site produced mean dry matter yields of 22.8, 21.3, 20.9, 19.3, 18.4, and 10.0 $Mg\,ha^{-1}\,y-^{1}$, respectively (averaged over the last two years). Dry matter yields at the Coastal site for giant reed, giant miscanthus, switchgrass, ravenna grass, and 'Gracillimus' were 27.4, 20.8, 20.1, 14.3, and 9.4 $Mg\,ha^{-1}\,y^{-1}$, respectively (averaged over the last two years). Increasing N rates up to 134 $kg\,N\,ha^{-1}$ did not have a consistent significant effect on biomass production. High yields coupled with high mortality for plume grass at both sites indicates its potential as a bioenergy crop and need for continued improvement. Overall, the perennial grasses in this study had low nutrient removal, although giant reed and plume grass often removed significantly more N, P, K and S compared with *Miscanthus* spp. and switchgrass. Our results indicate that giant reed, giant miscanthus, and switchgrass are productive bioenergy crops across geographic regions of North Carolina.



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## 1. Introduction

Many woody and herbaceous feedstocks exist for potential development and optimization within the emerging bioenergy sector. However, international interest in production systems utilizing perennial grasses has positioned a suite of perennial grasses as strong candidates for dedicated lignocellulosic bioenergy crops. These grasses have high biomass yields, low input requirements [1–3], are productive on marginal land, and provide ecological benefits including soil improvement [4], increased carbon sequestration [5], and wildlife habitat [6,7]. In some cases, perennial grasses have been projected to produce more than twice the amount of ethanol per hectare than maize grain [8]. While many perennial grasses are being explored for use as bioenergy crops, certain taxa in *Miscanthus*, *Saccharum* (*Erianthus*), *Panicum*, and *Arundo* have garnered particular attention as high producing, low-input energy crops, with great potential for improvement and optimization.

*Miscanthus* contains approximately 14–23 species of tall, warm season $C_4$ grasses native to East and South East Asia [9,10]. *Miscanthus sinensis* Anderss., *Miscanthus sacchariflorus* (Maxim.) Franch., and *M.* × *giganteus* Greef & Deuter, are of significant interest as bioenergy crops for a variety of reasons including high biomass yield and high N and water use efficiencies [10–12]. Generally, nitrogen (N) fertilization does not appear to increase biomass production in *Miscanthus* [11]. When N fertilizer treatments are found to influence biomass production, they generally have a limited positive effect which is usually apparent only after the first two years of growth [13]. The primary limiting factor for increasing biomass production in *Miscanthus* is often soil water availability [10,12,14,15]. *Miscanthus* is reported to form symbiotic associations with $N_2$-fixing bacteria, which may account for the limited N fertilizer responses [16–18].

Giant miscanthus, *Miscanthus* × *giganteus*, ($2n = 3x = 57$) is a naturally occurring, highly infertile, triploid hybrid derived from diploid *M. sinensis* ($2n = 2x = 38$) and tetraploid *M. sacchariflorus* ($2n = 4x = 76$) [19]. Giant miscanthus produces dry matter biomass yields ranging from 5 to 38 Mg ha$^{-1}$ y$^{-1}$ in the United States [14,20–22] and 10–25 Mg ha$^{-1}$ y$^{-1}$ in non-irrigated European plots, although yields in excess of 30 Mg ha$^{-1}$ y$^{-1}$ have been reported for irrigated stands in southern Europe [23]. Giant miscanthus stands are usually derived from rhizome cuttings, which increase costs associated with propagation and field establishment compared with seed-established crops [11]. However, once established, stands can maintain productivity for at least 14 years [24]. While giant miscanthus has received significant attention in Europe and the US, costs associated with vegetative propagation and sensitivity to cold temperatures during establishment in some locations [23] limits its ubiquitous use as a bioenergy crop. Chinese silver grass, *M. sinensis*, has also shown promise, both as a source of genetic material for improvement and as a competitive bioenergy crop [9,15,25–27]. Cultivated Chinese silver grass has been reported to reach heights of 1–2 m and produce between 10 and 40 Mg ha$^{-1}$ y$^{-1}$ in Europe [26]. *M. sinensis* 'Gracillimus' is a popular dense, thin-leaved ornamental that reaches approximately 2 m in height and has shown high survival and biomass yields of 2–17 Mg ha$^{-1}$ y$^{-1}$ in Germany and 26.5 Mg ha$^{-1}$ y$^{-1}$ in Italy [27].

A close relative to *Miscanthus*, *Saccharum* contains approximately 6 species, and is dominated by robust rhizomatous $C_4$ cane grasses found mostly along riversides and in valleys or on open hillsides [28,29]. Certain members of this genus are already successful bioenergy crops, including conventional sugarcane (*Saccharum* spp. hybrids L.). More recently, high fibre energycanes [10] have demonstrated dry matter yields of 15.9–32.4 Mg ha$^{-1}$ y$^{-1}$ in Alabama [30], 2–15 Mg ha$^{-1}$ y$^{-1}$ in Arkansas [31], and 18.7 Mg ha$^{-1}$ y$^{-1}$in Georgia [32]. Improvement of energycanes for bioenergy production will only increase DM yields: F1 hybrid energycanes in Louisiana yielded an average of 46.1 Mg ha$^{-1}$ y$^{-1}$while elite, parental lines in the same trial yielded only 28.6 Mg ha$^{-1}$ y$^{-1}$ [33]. While sensitivity to winter temperatures limits the use of many *Saccharum* representatives to tropical and sub-tropical regions [30], more cold-hardy members of *Saccharum* (sometimes classified as *Erianthus* spp.) may be useful in temperate regions, including *Saccharum arundinaceum* Retz., plume grass, and *Saccharum ravennae* (L.) L., ravenna grass. These stout, reedy, cold-hardy tufted canes are native to temperate and tropical Asia, India and China and produce large quantities of above-ground biomass. However, documentation concerning yield potential and cold hardiness of plume grass and ravenna grass is limited.

*Panicum virgatum* L., switchgrass, is a vigorous, spreading, sod-forming $C_4$ grass, native to North America where it is a common member of the tall grass prairies of the Central Plains. Switchgrass exhibits considerable genetic diversity [34–36] and includes two distinct ecotypes: the lowland tetraploid ($2n = 4x = 36$) ecotype and the upland octaploid ($2n = 8x = 72$) ecotype [37]. Improvement and selection of cultivars for conservation and forage purposes in the US began in the 1930s, and in the 1990s the US Department of Energy began investigating switchgrass as a potential bioenergy crop. Switchgrass was originally selected for conservation purposes and bioenergy production because it is native, perennial, adaptable, palatable to livestock, has documented and well-understood establishment and management practices, and is a crop with which many farmers have some familiarity [38]. Production trials led to the determination of the best commercial varieties, of which 'Alamo', a lowland variety, was selected for its ability to thrive in the southern United States [38]. Switchgrass dry matter yields reportedly span 1–40 Mg ha$^{-1}$ y$^{-1}$ [39] with the majority of reported yields ranging from 10 to 14 Mg ha$^{-1}$ y$^{-1}$ [39]. Switchgrass has been shown to respond to N fertilizer applications, however annual N requirements are relatively low with optimum dry matter yields reported from stands treated with 40–224 kg ha$^{-1}$ N fertilizer depending on the site, harvest regime, cultivar, and stand age [38,40–42]. Switchgrass can be established from seed and stands usually require 3 years to reach productive maturity [37]. As with *Miscanthus*, $N_2$ fixing bacterial endophytes have been implicated in the high N use efficiency of switchgrass [37,43]. Response to phosphorus (P) is variable, although some reports indicate that switchgrass will respond to P additions in conditions where soil-available P is low [42].

Giant reed, *Arundo donax* L., is a $C_3$, densely culmed, emergent riparian cane grass that forms clonal stands with an