Biomass Yield and Nitrogen Response of Perennial Bioenergy Grasses in North Carolina

Irene E. Palmer, Thomas G. Ranney, Ron Gehl, Darren Touchell, and Nic George

North Carolina State University, Department of Horticultural Science and Department of Crop Science, Mountain Horticultural Crops Research and Extension Center
455 Research Drive, Mills River, NC 28759
Department of Horticultural Science, North Carolina State University, 214 Kilgore Hall, Campus Box7 609, Raleigh, NC, 27695 & The North Carolina Solar Center
1575 Varsity Drive, North Carolina State University, Raleigh, NC 27606

iepalmer@ncsu.edu

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Significance to Industry: Bioenergy production draws from a wide range of potential raw materials and transformation processes, providing flexible solutions to increasing global petroleum scarcity (1). Perennial grasses (PGs) are attractive candidates for bioenergy production that can exhibit substantial biomass yields (2), require relatively few inputs, and provide a variety of ecological benefits (3-5). However, adaptability and yield of PGs can vary considerably by region (6-8). Because candidate PGs are diverse and information on regional yields and suitability is often lacking, an assessment of performance under different conditions is an integral component of the transition towards large scale bioenergy production. In this study, biomass yield, nitrogen response, and regional suitability of selected PGs were evaluated over three years at two locations in North Carolina as part of an ongoing effort to develop improved plants and production practices.

Nature of Work: A number of PGs have received considerable attention as potential bioenergy crops, including *Miscanthus*, *Panicum*, *Arundo* and *Saccharum* members. *Miscanthus* contains approximately 14 species of tall, warm season C4 grasses native to South East Asia that exhibit high light absorption rates and high nitrogen and water use efficiencies (9, 10). Generally, nitrogen fertilizer treatments do not increase biomass production in *Miscanthus*, and the primary limiting factor is often water availability (9-12). *Miscanthus sinensis* 'Gracillimus,' a popular ornamental, yielded 5.5 $T{\cdot}A^{-1}$ in production trials in Germany (13). *Miscanthus ×giganteus* is a naturally occurring sterile triploid hybrid derived from diploid *M. sinensis* and tetraploid *Miscanthus sacchariflorus* (14). This hybrid has been reported to yield between 8.9 and 14 $T{\cdot}A^{-1}$ in Illinois, and is one of the most highly studied PGs for bioenergy applications (15). *Panicum virgatum* is a native vigorous, spreading, sod-forming C4 grass. *Panicum virgatum* 'Alamo,' a lowland variety, was selected for its ability to thrive in the South (16). In North Carolina various *P. virgatum* cultivars have been found to produce 5-6.4 $T{\cdot}A^{-1}$ (17, 18). *Arundo donax* is a C3 riparian cane grass that forms densely packed monotypic stands. *Arundo* *donax* has been shown to respond favorably to N fertilizer applications in some instances and yield data from Italy found that *A. donax* can produce approximately 13.4 $T{\cdot}A^{-1}$ (19). *Saccharum arundinaceum* and *S. ravennae* are stout, reedy, cold-hardy C4 canes, native to temperate and tropical Asia, predominantly India and China (20). Reliable yield data for these species is lacking.

The seven taxa selected for this study were: *Arundo donax, M. ×giganteus*, *M. sinensis* H2006-006-001, *M. sinensis* 'Gracillimus', *S. ravennae*, *S. arundinaceum*, and *P. virgatum* 'Alamo'. *Miscanthus sinensis* H2006-006-001 is a breeding line selected for evaluation based on initial performance in Western North Carolina. The objectives of this study were to determine the biomass yield, nitrogen response, and regional adaptability of the aforementioned taxa as part of a larger effort to develop dedicated energy crops appropriate for the region.

Trial Establishment: In the spring of 2008, field trials were established in Mills River (Mountain) and Williamsdale (Coastal Plain), North Carolina. Both sites were treated with herbicide (glyphosphate), tilled, and conditioned with 1 $T{\cdot}A^{-1}$ of preplant lime. The experimental design was composed of seven taxa and four nitrogen treatments (0, 30, 60, 120 lbs $N{\cdot}A^{-1}$) arranged in a completely randomized factorial containing 28 plots at each of the two locations. In June 2008, plugs of each taxon were planted in 16.4 x 16.4ft plots that contained 25 plants in five rows with plants spaced 3.28ft apart, with the exception of *P. virgatum* 'Alamo' which was seeded in 12 inch rows at a rate of approximately 7.12 $lbs{\cdot}A^{-1}$. Bare-ground aisles 6.56 ft wide were maintained between the plots. Both sites received irrigation as needed for the first 3 months after planting. In July 2008, crab grass was removed manually and 2,4-dichlorophenoxyacetic acid (2, 4-D) was applied for broad leaf weed control. After year 1, little weed control was required and no irrigation was supplied. Nitrogen (ammonium nitrate, 33.5 - 0 - 0) was broadcast annually in the spring at the rates described previously. Plots were harvested in late December/early January of 2008, 2009 and 2010. Survivability data was recorded at that time.

Harvest: Nine plants, selected from the interior 9.8 x 9.8ft area of each plot, were cut at approximately 1.6 in from the ground and weighed fresh, with the exception of *P. virgatum* 'Alamo' and *A. donax* whereby the entire interior 9.8ft x 9.8ft square was cut and weighed. Plants located within the guard rows that fell outside of the 9.8ft x 9.8ft block were also cut and removed during sampling. Approximately 2 lbs of ground plant material, derived from the 9 subsamples per plot, was selected at random, ground, weighed, oven dried at 113°F for 72 hours and reweighed to determine fresh to dry weight ratios. Adjusted yields corrected for any dead/missing plants and were calculated as: yield x (potential area (96.04ft^2)/actual plant-filled area).

Data analysis: Survival and yield were analyzed for significant differences by analysis of variance (PROC GLM, SAS Institute, Cary, N.C.) with nitrogen rate and year designated as continuous variables.

Results and Discussion: *Survival:* At the mountain site, *M. ×giganteus*, *M.* 'Gracillimus', H2006-006-001, *P. virgatum* 'Alamo,' and *A. donax* had greater than 90% survival through harvest in late December 2010. Survival at this site for both *Saccharum* species was considerably lower at 69% for *S. ravennae* and 25% for *S. arundinaceum* (and was excluded from yield analysis as a result). *Saccharum arundinaceum* has been reported to survive in USDA hardiness zone 7, though more investigation as to its cold-hardiness in zone 6 and colder is needed (20). Based on high mortality rates in 2009, Zone 6b may reflect the marginal limit of this taxon's cold hardiness. At the coastal plain site, *M. ×giganteus*, *S. ravennae*, *P.* 'Alamo,' and *A. donax* had greater than 90% survival while *M.* 'Gracillimus', *S. arundinaceum* , and *M*. H2006-006-001 had survival rates of 86, 81, and 22% (and was excluded from yield analysis as a result), respectively.

Yield: Dry matter biomass production was influenced by multiple interactions between nitrogen rate, location, taxa, and growing year, though the simple effect of nitrogen rate alone was generally not significant. There were three exceptions at the coastal plain site in 2010 where *S. arundinaceum* (p=0.053), and *S. ravennae* (p=0.039) and *A. donax* (p=0.056) had a significant positive linear response to nitrogen rate. Lack of nitrogen response in the *Miscanthus* representatives is consistent with the literature (9, 12) and life history characteristics of the genus, including symbiotic N fixation and nutrient cycling to rhizomes (9). In some instances, *P. virgatum* has been shown to respond to nitrogen fertilizer applications, but no response was seen in this study (17).
At the mountain site in 2010, *M. ×giganteus*, *M. sinensis* 'Gracillimus' and'H2006-006-001, *P.* 'Alamo,' and *A. donax* produced the greatest amount of biomass, between 8.47 and 9.86 $T \cdot A^{-1}$. At the coastal plain site in 2010, *S. arundinaceum* and *A. donax* produced the most biomass with 15.17 and 13.15 $T \cdot A^{-1}$, respectively. The Billion Ton Study (2005) estimated that 40-60 million acres of pasture and farmland could be replaced to produce 150-380 million dry tons of biomass assuming annual yields of 5-8 dry $T \cdot A^{-1}$. There were six taxa capable of producing more biomass than this required minimum yield, at either the mountain or coastal plain sites.
Results from this study indicate that certain taxa of *Miscanthus, P. virgatum*, *S. arundinaceum*, and *A. donax* are promising bioenergy crops for certain locations in North Carolina and other similar regions, and are able to meet national dry matter production benchmarks. A better understanding of the agronomy of emerging bioenergy crops will be key in elucidating efficient production strategies, and continued evaluation and improvement of these crops with a focus on taxa appropriate for the SE United States may position the region to be competitive in the emerging bioenergy sector.

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