Responsiveness of Miscanthus and Switchgrass Yields to Stand Age and Nitrogen Fertilization: A Meta-regression Analysis

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Project Goals

This study examines the productivity response of bioenergy crops to various agronomic, climatic, and management factors. We estimate production functions for miscanthus and switchgrass in generalizing the combined response of N fertilization and stand age on harvestable biomass controlling for soil productivity, climatic factors, and experimental variabilities. One implication of the predicted yield response is to guide the existing biophysical (mechanistic) growth models for improved yield modeling through validation. Furthermore, the yield estimates will serve as a benchmark for regional bioenergy assessment models which heavily rely on relative profitability of these crops for mapping land use change.

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Abstract

Motivation: Ambitious cellulosic biofuel mandates in the U.S. require continuously updated information on productivity response of dedicated energy crops such as miscanthus and switchgrass to numerous climatic, agronomic and management factors. Research has shown that these crops perform relatively better in marginal growing conditions compared to row crops. Studies have also provided evidence of ecosystem benefits of these crops, including increased soil carbon, reduced N_2O emissions, and reduced NO_3 leaching, compared to row crops. These crops are considered as sustainable energy sources mainly because of their high productivity and nutrient use efficiency, including the ability to recycle nutrients annually. However, depending on soil and climate, input requirements of these crops are expected to vary spatially and temporally. Among other factors, optimal N use is of much significance since excessive application not only leads to economic inefficiency but may become counterproductive by releasing N_2O emissions and NO_3 leaching, which have well known GHG implications. As perennials, these crops have establishment, growth, and senescent phases which all differ in harvestable biomass, which again depend on climatic and management factors. Thus, growth consideration in terms of productivity and optimal rotation have economic significance because of an extended waiting period to start realizing profits. The primary objective of this study is to develop an empirical model and estimate using a suite of meta-analysis econometric techniques to explain the productivity response of perennial energy crops to climatic, agronomic, and management factors including N and stand age, simultaneously capturing the study and location-specific experimental variabilities as well as their differences across harvest years, effectively capturing study and location-specific temporal dependencies in yield measurements.

Data and Methods: The datasets in the analyses include a total of 1,884 yield observations of miscanthus obtained from 27 locations in 14 states, and 2,903 yield observations

of switchgrass obtained from 23 locations in 15 states from the U.S. For each plot-level observation, dry biomass yield (Mg ha^{-1}), location, latitude and longitude, planting year, growing year, plot size (m^2), planting method, planting density (ha^{-1} or kg ha^{-1}), harvest year, N application rate (kg ha^{-1}), and cultivar (switchgrass) are directly extracted from texts and tables of the published articles or datasets obtained through personal communications. The data we have collected has clustered structure with yield measurements taken at various levels, i.e. study, location, and year. Furthermore, each study and location has repeated observations for a specific year attributed to harvests from multiple replications. Thus, an econometric technique within the multi-level meta-regression context is applied to correctly address the cross-sectional (locations) and temporal (years) dependencies among repeated observations from the same study in estimating production functions.

Results: Using appropriate functional forms and interactions for N and age, we found that the yield of miscanthus varies over N rates with substantial differences between the matured and older stands (Fig. 1). For example, without N, mean predicted yields of 6th and 10th year stands are 22.92 and 9.41 Mg ha^{-1}, respectively; yields increased to 28.37 and 19.10 Mg ha^{-1}, respectively, with 225 kg N ha^{-1}, with further increments to 30.82 and 25.79 Mg ha^{-1}, respectively, with 450 kg N ha^{-1}. The increased yield response to N of older age stands support some of the earlier findings that the decline in productivity, to some extent, can be offset with additional N fertilization. However, the differences in switchgrass yields with increasing N rates for the matured and older plants are quite identical. Specifically, plants at various stages of maturity showed an increasing response to N up to a specific level and then followed a declining trend with further increase (Fig. 2). For example, without N, mean predicted yields of 6th and 10th year stands are 8.39 and 5.81 Mg ha^{-1}, respectively; yields increased to 14.69 and 12.99 Mg ha^{-1}, respectively, with 200 kg N ha^{-1}, and then slightly decreased to 13.88 and 12.39 Mg ha^{-1}, respectively, with 250 kg N ha^{-1}. A general conclusion that can be drawn from the predicted yield response of age and N interaction, controlling for study, location, climatic, and management factors is that the yield maximizing N rate varies for miscanthus whereas it remains fairly identical for switchgrass over the maturity stages.

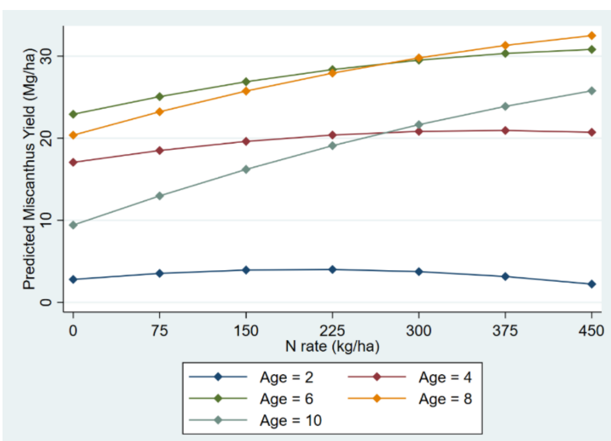

Fig 1. Predicted miscanthus yield

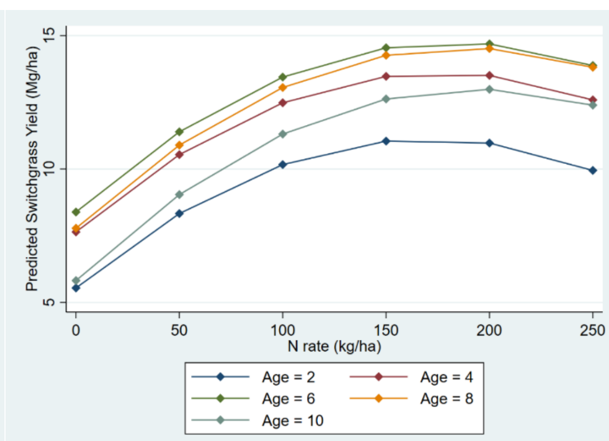

Fig 2. Predicted switchgrass yield

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