Title: Determining Profit-Maximizing Dynamic Mix of Nitrogen Rate and Stand Age in Miscanthus and Switchgrass Production

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Project Goals: The purpose of our research is to determine the profit-maximizing N application rate at different stand ages and the optimal stand age for field replanting in miscanthus and switchgrass (Alamo, Blackwell and Cave-In-Rock) production in the rainfed region of the United States. Profit-maximizing N application rate over stand ages and optimal stand age for field replanting are critical management decisions faced by a landowner, but there have been limited pieces of evidence in the literature. A few previous studies have examined the profit-maximizing N rates using short-term field-level data. A major limitation of these studies is that they estimate the profit-maximizing N by calculating net returns of constant N treatment rates applied annually over the years in the field trials. However, recent studies show that N requirements change at different maturity stages as yield responsiveness to N changes (Sharma et al., 2021). We extend this literature with estimating the dynamic profit-optimal N application rate and the profit-optimal lifespan of producing these energy crops. Results of our research can guide the profitable production of these two perennial energy crops by improving N rate recommendations and optimal replanting times.

Abstract Text: The benefits of producing perennial energy crops depend on market prices, production costs, and crop yields which may rely on climatic conditions, soil productivity, and management practices, especially nitrogen (N) fertilizer. Profitable production of these perennial energy crops requires understanding the yield response to management practices, especially the application of N fertilizer and the interaction with stand age (Sharma et al., 2021). We firstly propose a dynamic optimization framework where the landowner's objective is to maximize the net present value (NPV) of a stream of future benefits from producing perennial energy crops instead of conventional crops by choosing the optimal N application rate for different stand ages and the optimal stand age for field replanting. We use a generalized yield response function including N input, stand age and other factors such as weather and soil productivity for both miscanthus and switchgrass. Theoretically, we derive the optimal N application rate for each stand age given market prices and a set of parameters of the yield response function. Furthermore, we derive the optimal stand age that maximizes the NPV for field replanting. Next, we conduct numerical simulations in 2287 counties in the rainfed region (east of the 100th meridian) of the United States under six assumption scenarios: (1) baseline scenario (biomass price \$70 Mg^{-1} , discount rate 4%); (2) higher biomass price (\$90 Mg^{-1}), (3) higher biomass price (\$110 Mg^{-1}); (4) higher Discount Rate (10%); (5) 50% increase in N price; (6) 50%

increase in land rent. In the numerical model, we apply the yield response function parameters from Sharma et al. (2021) and use weather, soil productivity, and production costs data at county level.

We find that the profit-maximizing N application rate varies over stand ages for miscanthus. Under the baseline scenario, on average, the profit-maximizing N application rate for miscanthus increases continuously from 10.81 kg^{-1} ha^{-1} at stand age 2 to 165.76 kg^{-1} ha^{-1} at stand age 11, then slightly declines at older stand ages. In contrast, the profit-maximizing N rate for switchgrass maintains relatively stable (around 150 kg^{-1} ha^{-1} yr^{-1}) after establishment. There are only marginal differences in the profit-maximizing N application rate among these three cultivars(Alamo, Blackwell and Cave-In-Rock). Moreover, at younger stand ages, miscanthus requires a lower profit-maximizing N application rate than switchgrass, but the yield of miscanthus is higher than that of switchgrass. For middle-aged stands, switchgrass reaches almost the same high yield level as miscanthus while maintaining the same profit-maximizing N application rate as it is at younger stand ages. The profit-maximizing N application rate of these perennial energy crops over stand age is sensitive to the prices of biomass and N fertilizer, but it is not sensitive to discount rate and the land rent. Furthermore, on average, the optimal replanting stand age of miscanthus is 13 years, achieving the maximum NPV of \$2065 ha^{-1} (equivalent ANPV is \$203 ha^{-1} yr^{-1}). For switchgrass, on average, the optimal replanting stand age is 9 years for Alamo and Blackwell, and 8 years for Cave-In-Rock. The corresponding maximum NPV of producing Cave-in-Rock, Alamo, and Blackwell is \$1164 ha^{-1} yr^{-1}, \$1560 ha^{-1} yr^{-1}, and \$2303 ha^{-1} yr^{-1} (equivalent ANPV is \$162 ha^{-1} yr^{-1}, \$181 ha^{-1} yr^{-1}, and \$274 ha^{-1} yr^{-1}) averaged at county level, respectively. In biophysical models, the common assumptions are that the productive life span is 15-20 years for miscanthus and 10-15 years for switchgrass, which is longer than the optimal lifespan estimated from the economic perspective. Estimates of profit-maximizing N application rate, predicted yield, and ANPV of these two perennial energy crops also vary across geographic regions. These results imply that recommending the optimal N application rate over stand ages and across regions will help improve the economic benefits of producing perennial energy crops.

References/Publications

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