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Nitrogen use in switchgrass grown for bioenergy across the USA

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ABSTRACT

The effect of nitrogen (N) fertilizer on switchgrass biomass production has been evaluated in a number of locations on a small-plot scale; however, field-scale information regarding switchgrass response to N and N use efficiency (NUE) in different regions of the USA is limited. Switchgrass was planted in South Dakota (SD), New York (NY), Oklahoma (OK), and Virginia (VA) in 2008 and in Iowa (IA) in 2009. Three N levels (0, 56, and 112 kg ha^{-1}) were applied to 0.4–0.8 ha plots at each location beginning in spring the year after planting. Biomass production, N removal, apparent N recovery (ANR), and NUE were determined at all locations. Biomass yield response to N varied among locations and varied according to initial soil N concentration. Low initial soil N concentration increased biomass yield response to N fertilization, while high initial soil N concentration reduced this response. High amounts of initial soil N caused fertilizer N removal to be low. Fertilizer N uptake in switchgrass might be inhibited by competition from initial soil N. Seasonal temperature and precipitation were not strongly correlated with biomass yield and N-use of switchgrass at the studied locations. In this study, ANR was below 10% at all locations and years. Nitrogen-use efficiency was significantly related to initial soil N. High NUE was observed at locations where initial soil N was low. These data suggest that NUE depends on site-specific N management strategies that are responsive to soil N supply and plant N status.

1. Introduction

Switchgrass has been extensively studied for its value as a forage, conservation, and bioenergy crop [1–5]. It offers a number of distinct benefits including broad adaptation, improved soil conservation and quality [2,6], reduced greenhouse gas emissions [7], and carbon sequestration [6,8–10]. In particular, it has high yield potential on land marginal to row

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crop production [11]. In previous work in South Dakota USA, Mulkey et al. [11] found that switchgrass grown in marginal soil was well suited for sustainable biomass energy production.

Although switchgrass tolerates low soil fertility, optimizing biomass and maintaining quality stands requires nitrogen (N) fertilizer inputs and proper management. Switchgrass responds positively to N fertilization, but its response varies with regional environment and soil fertility. Switchgrass biomass increased with increasing N rates up to 168 kg ha^{-1} in low organic matter and low fertility soils in Texas USA [3], and Vogel et al. [5] reported that 10–12 kg ha^{-1} of N was required to produce one tonne per hectare of switchgrass biomass in the Midwestern USA. However, Mulkey et al. [11] reported no benefit with N application levels above 56 kg ha^{-1} on switchgrass-dominated Conservation Reserve Program (CRP) lands in South Dakota, USA. A major question regarding switchgrass management as a bioenergy crop is optimizing N application level. Excessive N fertilization may result in adverse environmental and economic effects, including accelerated N_2O gas emission, NO_3 leaching, and an increase in production costs.

The amount of N removed in biomass is important in determining fertilization needs and usefulness as a feedstock. Matching the N application level with N removal has obvious agronomic, economic, and environmental value. Bransby et al. [12] fertilized switchgrass with 100 kg ha^{-1} of N annually four years in the Southeastern USA, and an average of 87 kg ha^{-1} of N was removed in biomass from the field during the last three. Stout and Jung [13] reported fertilizer N recovery of about 31% and 23% following switchgrass fertilization at 90 and 180 kg ha^{-1} y^{-1} in Pennsylvania USA. However, Lemus et al. [14] reported annualized recovery values of 10%–25% per year with N application at 90–270 kg ha^{-1} in Virginia USA.

There are two general types of switchgrass cultivars characterized as lowland and upland. Lowland cultivars are vigorous, tall, thick-stemmed, and adapted to wetter conditions whereas upland cultivars are short, rhizomatous, thin-stemmed, and adapted to drier conditions [15]. The physiological differences between the two switchgrass types may result in different yield performance in the same environment. Stroup et al. [16] reported that the lowland cultivars produced greater biomass yields than upland cultivars in a test conducted in the greenhouse. Nitrogen requirements may also differ between the two cultivars. Clyder and Porter [17] reported that lowland cultivars of switchgrass had a lower nitrogen requirement than upland cultivars.

So far, direct comparisons of N fertilization in replicated studies of switchgrass across the USA are limited. This study is one segment of the Regional Feedstock Partnership, a program funded by the US Department of Energy and administered by the Sun Grant Initiative, which was designed to evaluate dedicated herbaceous energy crops and CRP land across environmental gradients in the USA. Specifically, the research reported in this paper provides more information of switchgrass N-use to improve N management in switchgrass grown for bioenergy across various regions of the USA. To do this, we determined 1) switchgrass yield response to N fertilizer; 2) N removal in switchgrass biomass; 3) apparent N recovery (ANR) and NUE of switchgrass grown in different regions of the USA.

2. Materials and methods

2.1. Site description

This study was conducted at five locations across the USA including South Dakota (SD), New York (NY), Iowa (IA), Oklahoma (OK), and Virginia (VA). The SD location was near Bristol, SD USA (45°16′ 8.274″N; 97°50′8.9694″W) on a Nutley-Sinai (silty clay, mixed, Chromic Hapluderts) with 2–20% slope; the NY location was near Tompkins, NY USA (42° 27′ 44.5896″ N; 76° 27′ 38.1882″ W) on an Erie channery (fine-loamy, mixed, mesic Aeric Fragiaquepts) with 2–8% slope; the IA location was near Ames, IA USA (41° 58′ 59.001″ N; 93° 41′ 50.0346″ W) on a Clarion-Nicolette (fine-loamy, mixed, mesic Typic Hapludolls) with 0–9% slope; the OK location was near Muskogee, OK USA (35° 44′ 32.9994″ N; 95° 38′ 21.12″ W) on a Parsons-Carytown (fine, mixed, thermic Mollic Albaqualfs-Albic Natraqualfs) with 0–3% slope; and the VA location was near Pittsylvania, VA USA (36° 55′ 56.2656″ N; 79° 11′ 23.8842″ W) on a Mayodan (fine sandy loam, mixed, thermic Typic Hapludults) with 2–15% slope. Seasonal temperature and precipitation data in 2009 and 2010 were collected from weather stations at each location (Tables 2 and 3).

2.2. Experimental design and field management

A locally adapted switchgrass cultivar was planted at each location. 'Sunburst' (SD), 'Cave-in-Rock' (NY and IA), 'Blackwell' (OK), and 'Alamo' (VA) were planted on 17 May 2008 (SD), 29 May 2008 (NY), 8 May 2009 (IA), 2 September 2008 (OK), and 1 July 2008 (VA). Experimental design was a randomized complete block with four replications across the landscape. Individual plot size ranged from 0.4 to 0.8 ha to allow for use of conventional agricultural equipment. Three levels of N fertilizer (0, 56, and 112 kg ha^{-1}) were applied annually beginning the year after establishment at all locations. Switchgrass was harvested once annually around a killing frost the year after establishment (Year 1) and the second year after establishment (Year 2) for SD, NY, OK, and VA. Since the IA location was planted in 2009, only Year 1 (2010) data are included. Harvest dates were 28 Oct. 2009 and 5 Nov. 2010 for SD, 22 Oct. 2009 and 2 Nov. 2010 for NY, 18 Nov. 2010 for IA, 13 Nov. 2009 and 28 Oct. 2010 for OK, and 10 Jan. 2010 and 10 Jan. 2011 for VA. Rain and delayed senescence of switchgrass biomass precluded fall harvest in VA; therefore, switchgrass was harvested in January of the following year when soil conditions were conducive to harvest equipment.

2.3. Biomass yield

Yield was determined by harvesting a windrow through the center of each plot (5.5 m × 360 m) with locally available equipment at a height of 10–15 cm. Biomass from each windrow was baled and weighed. Subsamples (approximately 300 g) were collected with a hay probe (1.3–1.9 cm wide × 45.7–61.0 cm depth) from the center of bales for