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Full Length Research Paper

Switchgrass response to nitrogen and phosphorus during first growth after seeding

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ABSTRACT

Switchgrass (*Panicum virgatum* L.) is a high-yielding, native perennial that could serve as a biofuels feedstock. The objectives of this research were to establish switchgrass' responses to N and P under well-defined, soilless conditions and to measure its fertilizer recovery. 'Cave-in-Rock' switchgrass was grown from seed in the greenhouse in a 2:1 (v/v) vermiculite:perlite substrate. Treatments (nine rates of N up to 400 kg N ha^{-1} and four rates of P up to 90 kg ha^{-1}) were replicated three times in a randomized complete block design. In a second study, treatments from two N sources (ammonium sulfate and urea) were applied at rates up to 270 kg N ha^{-1}. In both studies, plants were harvested 12 wk after germination, dried, weighed, and analyzed for tissue N and P concentrations. Shoot biomass increased with N fertilization up to 210 kg N ha^{-1}. In these pot studies, root biomass increased with N only to 100 kg N ha^{-1}. No significant effect above 30 kg P ha^{-1} was observed in shoot or root biomass. Biomass and tiller number were highly correlated. Increases in tillers plant^{-1} were observed up to 116 kg N ha^{-1}. Shoot and root N concentrations generally increased with fertilization. Ammonium sulfate had a greater effect than urea on shoot and root biomass. In field studies found in the literature, maximum yields have been obtained with as little as 50 kg added N ha^{-1} to as much 744 kg N ha^{-1}.These data suggest switchgrass can maximize biomass production with ~200 kg available N ha^{-1}.

Keywords: biomass; native grasses; feedstock; nutrient management; fertilizer use efficiency; *Panicum virgatum* L.

INTRODUCTION

Switchgrass (*Panicum virgatum* L.), a native warm-season species found throughout much of the southern and central US, has potential as a biofuels feedstock (Lemus et al., 2008). Fertility recommendations for switchgrass production apply mainly to forage production (Muir et al., 2001), where there is a compromise between maximum biomass production and peak forage quality. In energy cropping, this compromise is unnecessary because the main goal is to maximize production of lignocellulose (Sanderson et al., 1999a). Producing optimum switchgrass yields requires applying sufficient N for switchgrass growth without over-fertilizing. Too little N will not allow the crop to take full advantage of all other resources. Too much N can reduce yields by making plants more susceptible to diseases and insects and by increasing lodging (Lemus et al., 2008).

The precise N needs of switchgrass cannot be determined from field data because of the great variability of soils in supplying "endogenous" N. Nitrogen, which is highly mobile in the soil, is constantly undergoing transformations such as mineralization, leaching, volatilization, and immobilization. These dynamics undoubtedly contribute to the confusion in the literature regarding switchgrass' N response. Estimations of N requirements under soilless conditions will provide a more precise way to determine switchgrass N needs.

Although switchgrass has demonstrated high productivity across a wide geographic area, there is no consensus on fertilizer recommendations that would maximize yields (while ideally minimizing nutrient loss). Reported annual rates of N use for switchgrass (70 to 100 kg ha^{-1}) are typically about half of those required for corn production (138 to 154 kg ha^{-1}) (McLaughlin and Walsh, 1998). Several authors make N recommendations as low as 50 to 100 kg N ha^{-1} yr^{-1} (Wolf and Fiske, 1994; Bredja, 2000). In TX, Sanderson et al. (1999b) reported that the annual yield of several cultivars fertilized with 134 kg N ha^{-1} ranged from 8 to 20 Mg ha^{-1}. Others have shown responses in the field at up to 744 kg N ha^{-1} yr^{-1} (Lutwick and Smith, 1979).

Warm-season grasses generally have a lower N requirement and are more efficient users of P (Balasko et al., 1984). There are limited data on the effect of P fertilization on switchgrass and/or P interactions with other nutrients such as N. Depending on soil test and pH, P recommendations for switchgrass range from 0 to 35 kg ha^{-1} (Bredja, 2000). Griffin and Jung (1983) reported P stem tissue levels in switchgrass and big bluestem (*Andropagon gerardii* Vitman) decreased from 0.24% to 0.14% with increasing maturity. Radiotis et al. (1999) reported that P levels of the whole switchgrass plant fraction is 0.12% at **the** reproductive stage, but declined to 0.04% when standing biomass was left to overwinter. They suggested that P is either transported to the roots or leached out. Smith and Greenfield (1979) reported high P concentrations in switchgrass compared to timothy (*Phleum pratense* L.), with the highest P accumulation in the inflorescence. Research with some forage species and grain crops also indicates that rhizosphere microflora, particularly arbuscular mycorrhiza fungi, can enhance P uptake. Bredja et al. (1998) indicated that mycorrhiza populations collected in switchgrass fields increased P uptake by 37-fold across lowland and upland switchgrass ecotypes when compared to controls.

The N requirement for any crop is a function of the yield potential and the amount of N required per unit of yield. Stanford and Legg (1984) defined the N requirement as the minimum amount of N in the aboveground biomass associated with maximum production. Nitrogen use efficiency (NUE) provides a framework for evaluating variation in N-use factors as related to major plant physiological processes. Nitrogen use efficiency is an important topic when discussing fertilizer applications and switchgrass biomass production. The term NUE has been commonly used to describe the capacity of a plant to acquire and utilize N for increasing biomass yield (Gourley et al., 1994), but the definitions of NUE vary greatly (Clark, 1990). NUE generally can be divided into those emphasizing productivity (utilization efficiency) and those emphasizing the internal nutrient requirement of the plant (uptake efficiency) (Fiez et al., 1995). Uptake efficiency emphasizes the ability of a plant to take up supplied N, while utilization efficiency highlights the ability of N to increase yield. However, various N-use parameters could be misleading in the search for increased productivity and identification of mechanisms that enhanced nutrient acquisition and utilization (Buso and Bliss, 1988). With regard to yield parameters, nutrient efficiency has been defined as the ability to produce a high plant yield in a soil, or other media, that would otherwise limit production (Buso and Bliss, 1988).

The profitability of switchgrass as a biomass crop would be enhanced if acceptable yields can be produced with a minimum amount of applied N. The main objectives of study were: (1) to measure switchgrass responses to N and P under defined conditions, (2) to determined differences in switchgrass biomass under two N sources, (3) to determine NUE of switchgrass under different N sources and application rates and (4) to compare NUE parameters that could aid to make better recommendations on N applications.

MATERIALS AND METHODS

Two N fertilizations studies (A and B) were conducted in a greenhouse setting in August 2002 and September 2003. An artificial substrate containing 2:1 (v/v) mix of vermiculite and perlite was used in both studies. This artificial mixture was used, because it contained no N and very low levels of P. To determine water-holding capacity, pots (4.5 L) were filled with the substrate, saturated with tap water, and allowed to drain overnight. The drained weight was used to establish “field capacity.” The moisture content of the medium during the course of the study was adjusted by using Time Domain Reflectrometry (TDR) (ESI, Vancouver, B.C). Pots were weighed every 2 d depending on soil water content of the substrate as indicated by TDR readings, and water was added when necessary to adjust moisture content to 80% of field capacity. About 500 ml of water per pot were added every 2 d to maintain moisture once plants attained full size. Temperature was maintained to 32 ± 2 ºC during the day and 25 ± 2 ºC during the night. Plants were exposed to 14 hours daylight and 8 hours nighttime.

Fertilization rates for these studies were obtained from soil test recommendations for grasses and warm-season grasses across several states in the USA (ND, SD, KY, IA, VA, NY, and NC). The experimental design was a randomized complete block in factorial arrangement with three replications. The treatments included nine N rates (0, 50, 100, 150, 200, 250, 300, 350, or 400 kg ha^{-1}) and four P rates (0, 30, 60, or 90 kg N ha^{-1}) applied on a substrate-surface-area basis. Ammonium sulfate [(NH4)$_2$SO$_4$] and sodium phosphate (NaPO$_4$$^{\cdot}$ 7H$_2$O) were used as N and P sources, respectively. Pots were rotated periodically within blocks in both studies to allow similar changes to each pot at differences places.

In study B, urea (46-0-0) or ammonium sulfate [(NH$_4$)$_2$SO$_4$] was applied at of 0, 45, 90, 180, or 270 kg N ha^{-1}. A uniform 50 kg P ha^{-1} (as sodium phosphate) was applied at time of N applications. All fertilizer sources in both studies were dissolved in distilled H_2O and applied in solution. Plants of each treatment were watered once a week with 200 ml of a Peter's No-N/P (0-0-50) soluble trace element mix (STEM) (Peter's Co, Allentown, PA) to maintain an adequate level of K and micronutrients. The solution contains approximately 2 ppm K per application.

In both studies, Cave-in-Rock seeds collected in 1998 at the Virginia Tech turf grass research center were planted directly into 4.7 L undrained pots. Germination test (30 ^{o}C for 72 hr) conducted before the first study in July of 2002 showed that seeds were 74% germinable. Approximately 30 seeds were planted in each pot and thinned to eight plants per pot 3 wk after planting in the first study. For the second study, pots were thinned to ten plants per pot. Switchgrass plants were maintained in a 14-hr photoperiod in the greenhouse (using natural sun light as well as fluorescent light) and adequate temperature range. Some temperature fluctuations were observed in the greenhouse, since the cooling system was unable to maintain the set maximum temperature of 25 $^{\circ}$C. Study A was conducted from July to October and study B was conducted from July to November.

For both studies, biomass yields were determined at the heading stage [R1 (Moore et al., 1991)] (approximately 12 wk in the after planting). Shoots were harvested at the "soil" surface. Roots were separated from the medium by washing with tap water. All plant materials (above and belowground) were dried at 60 ^{o}C for 72 hr in a forced air oven for dry weight determinations. Tiller number per pot was divided by plant number to obtain the mean of tillers per plant. Plant materials were ground to pass a 2 mm screen in a Wiley Mill. Total N in aboveground and belowground samples was determined using the Vario Max CN analyzer (Elementar Analysensysteme GmbH, 2000).

Nitrogen content was calculated by multiplying biomass by the concentration of N. Nitrogen use efficiency (g g^{-1}) for each study was calculated as [(yield at N_x – yield at N_0)/g of N applied at N_x], where x = N rate > 0 (Zemenchik and Albretch, 2002; Novoa and Loomis, 1981). The apparent N recovery (ANR) was calculated using the difference method: ANR = [(g of N recovered at N_x – g of N recovered from N_0)/g N applied at N_x] X 100, where x=N rate >0 (Crasswell and Godwin, 1984). Partial factor productivity (PFP) (g g^{-1}) was calculated as $(Y_0 + \Delta Y)/N_x$, where Y_0 is the biomass yield at N_0 and ΔY is the increment in biomass yield that resulted from N application (Cassman et al., 1998).

Experimental design and statistical analysis

The experimental design in study A was a randomized complete block in factorial arrangement with three replications or blocks. The second study was a randomized complete block design with a split-plot design replicated four times. Fertilizer sources were considered the main plots and fertilizer rates were considered the sub-plots. Nitrogen rates were randomized within each block by following the PLAN procedure of SAS (SAS Institute, 2014).

Analyses of variance (ANOVA) were conducted using the GLM procedure of SAS (SAS Institute, 2014) at $P<0.05$ to test the effects of fertilizer sources and treatments. Means were separated by the least significant difference (LSD) at 0.05 probability level. The REG and CORR procedures of SAS (SAS Institute, 2014) were utilized to determine relationships between switchgrass components (yield, N concentration and content, tiller number, height, and N-use parameters) and N rates. A non-linear model known as a linear-plateau model that follows the NLIN procedure and the NEWTON method was also used for data analysis. The linear-plateau model is a manifestation of Liebig's law of the minimum where the rate of change in plant responses to changes in N applications is constant until certain yield or N concentration is reached, at which other nutrients become limiting and the response attains a plateau (Schabenberger and Pierce, 2002). The linear-plateau model calculates the point at which the relationship is no longer linear, and this point is called the join point of the model. Significance of both the linear and non-linear regression models was tested and the models with the strongest coefficients of determination were fitted to the data.

RESULTS AND DISCUSSION

Study A: Responses to N and P Fertilization

There were no differences in root and shoot biomass above 30 kg P ha^{-1} except at the 0 P treatments and no N x P interaction. Accordingly, data were combined across P rates (except for the 0 rate) to look at N responses. Nitrogen fertilization dramatically increased biomass yield in both shoots and roots (Figure 1). Differences in shoot biomass were observed past 250 kg N ha^{-1}. At 400 kg N ha^{-1}we might have reached the plateau in the response curve according to the linear-plateau model. Root biomass yield did appear to reach a plateau and much earlier at 114 kg N ha^{-1}. Shoot and root biomass increased in parallel up to 100 kg N ha^{-1}. After that, root biomass plateaued. This could be related to roots growing in a restricted pot environment, which might have affected their developmental physiology.

Applied N had an effect in switchgrass height and tiller density (Figure 2). Height increased up through a rate of 113 kg N ha^{-1} and plateau at higher N rates. Nitrogen had a linear effect on switchgrass height and tiller density. Tiller density showed an increase up to 300 kg N ha^{-1}. In this greenhouse, substrate setting, and at high N rates,

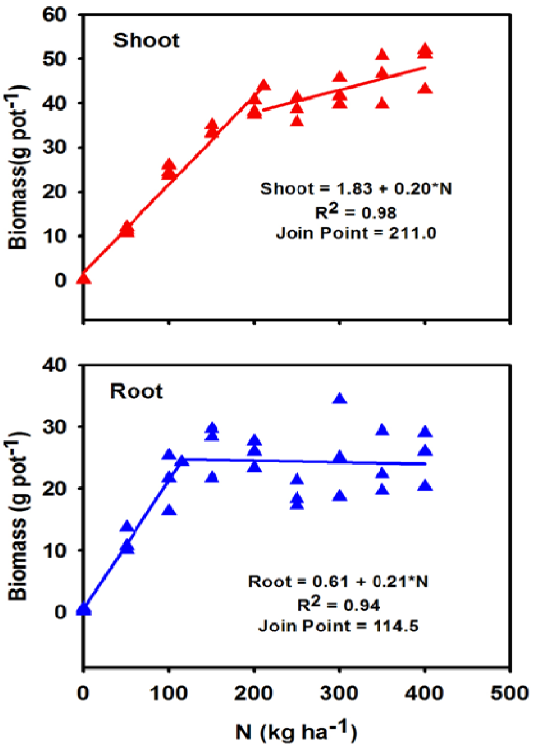

Figure 1. Effects of N fertilization on shoot and root biomass of seedling switchgrass grown in a greenhouse substrate (Study A).

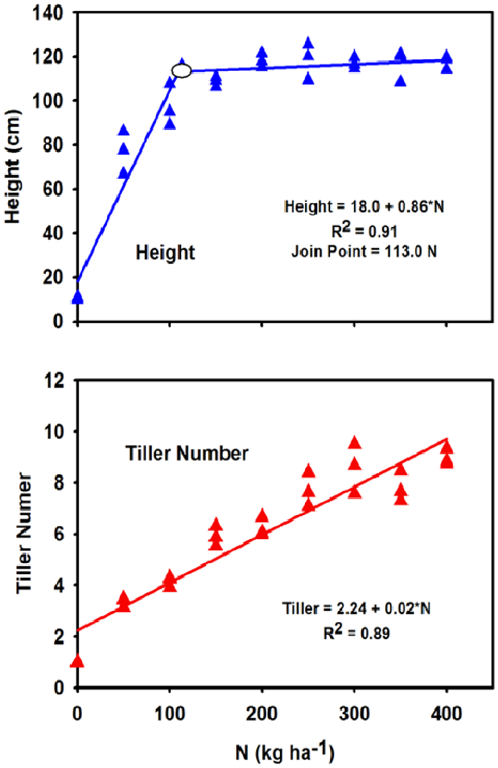

Figure 2. Effects of N fertilization on height and tiller number of seedling switchgrass grown in a greenhouse substrate (Study A).

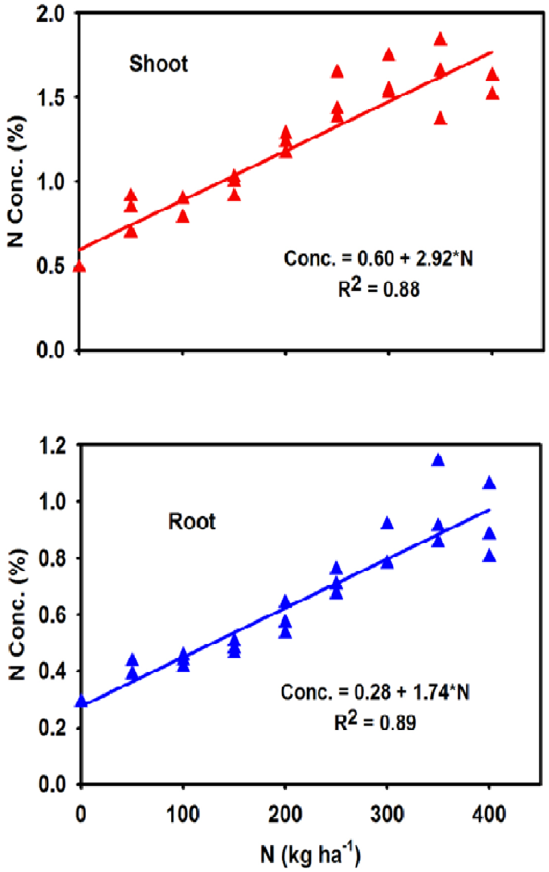

Figure 3. Changes on shoot and root N concentrations of seedling switchgrass grown in a greenhouse substrate under different N rates (Study A).

biomass yields were partially a function of increased tiller density per plant.

Nitrogen concentration in switchgrass tissue averaged about 90% higher in shoots than roots, but both increased linearly with applied N (Figure 3). This difference is expected for leafy material, which is inherently higher in protein. Differences in shoot N concentration increased with applied N up to 250 kg ha^{-1}. There did not appear to be “luxury consumption”, since yields continued to increase after tissue N levels stabilized.

Nitrogen content (mg N in biomass) in shoots increased steadily with increasing N applied up to 300 kg N ha^{-1} (Figure 4). Roots had a similar, if less dramatic, pattern. Especially at higher N rates, shoots had a much greater N content than roots, reflecting both greater biomass and higher N concentrations in the shoots. Also, since roots were growing in a restricted environment, root biomass and nutrient absorption could have been affected. Roots might be a greater sink for N storage in a field situation where they might compete better with shoots for biomass partitioning.

Efficient use of N is important to reach an optimum switchgrass biomass yield. Different N-use parameters (NUE, ANR, and PFP) were calculated to determine productivity (utilization efficiency) and internal nutrient requirements of the plant (uptake efficiency). Nitrogen-use efficiency, ANR, and PFP were significantly different across N application rates (Figure 5). Nutrient-use efficiency, which was maximal at 100 kg N ha^{-1}, and PFP tended to decline with increased N applications. These results are consistent with field studies in which highest NUE was reached at 112 kg N ha^{-1} (Lemus et al., 2008). In the current study, less than 20% overall of the applied N was recovered in biomass. Maximal ANR occurred at 200 kg N ha^{-1}, with its lowest values at 50 and 400 kg N ha^{-1}. These values are very similar to ANR values reported by Weiser and Smith (1988). Calculated PFP values followed the same trend as those observed with NUE. Partial factor productivity was maximal at 100 kg ha^{-1}.

N-use parameters are a good measure of switchgrass’ ability to produce yields with low N inputs. Apparent N recovery should be considered the best measure of N-use in switchgrass to assess its ability to produce feedstock. Apparent N recovery measures the amount of

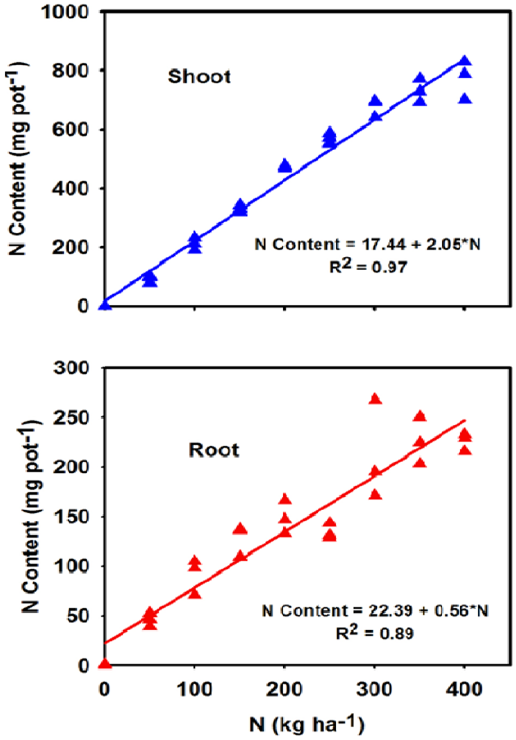

Figure 4. Changes on shoot and root N content of seedling switchgrass grown in a greenhouse substrate under different N rates (Study A).

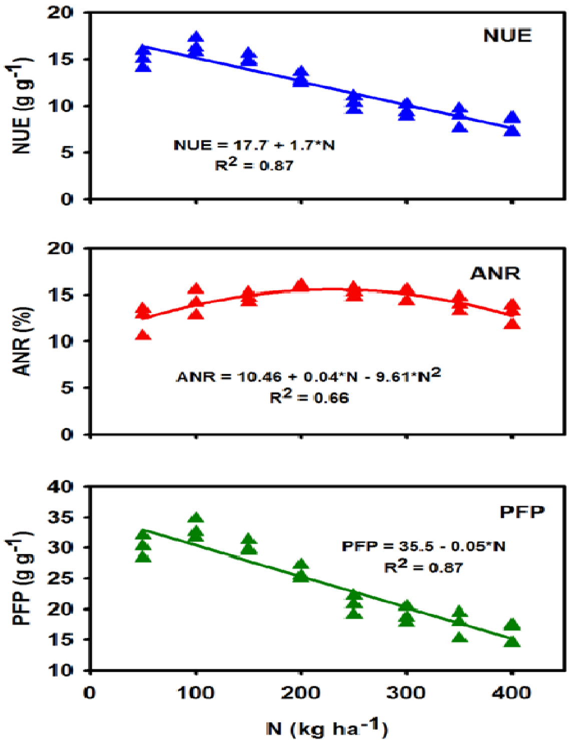

Figure 5. Effect of N rate on N-use efficiency (NUE), apparent N recovery (ANR), and partial factor productivity (PFP) of substrate grown switchgrass seedlings (Study A).

Table 1. Changes in switchgrass shoot and root biomass with applied N from two sources.

Part	Source	N (kg ha^{-1})					LSD$_{0.05}$[3]
		0	45	90	180	270	
		------ Biomass (g pot^{-1}) ------					
Shoot	AS[1]	0.2	8.8	15.4	15.6	17.2	2.9
	Urea	0.2	1.6	1.8	3.8	4.2	1.3
	LSD$_{0.05}$[2]	--	2.2	3.7	3.8	4.2	--
Root	AS	0.1	3.4	4.4	4.4	3.7	1.0
	Urea	0.1	0.6	0.7	1.3	1.2	0.4
	LSD$_{0.05}$[2]	-	1.4	1.4	1.9	0.6	--
	LSD$_{0.05}$[5]	-	1.2	2.5	1.6	5.1	--
	LSD$_{0.05}$[6]	-	0.7	ns	1.3	1.1	--

[1] Ammonium sulfate

[2] LSD for comparison of N sources within N rate and part.

[3] LSD for comparison of N rates within part and N source

[4] LSD for comparison of N sources within N rate.

[5] LSD for comparison of parts within AS and N rate.

[6] LSD for comparison of parts within Urea and N rate.

N removed in biomass. A bioenergy crop with low N and high biomass production will be preferable, since less NO_X compounds will be released in the combustion process. On the other hand, NUE or PFP do not take any account of losses from the production system, which can vary a lot; especially N, which can easily be volatilized, leached as nitrate, or lost by surface run-off. Both parameters, NUE and PFP, assume that under field conditions soil N dynamic changes during the season and could be considered as a reversible process and not a loss (Geber, 2000). The evaluation of N use in switchgrass should therefore be based on a value that includes total removals from the system. Apparent N recovery provides that capability, since it considers N removal from applied fertilizer or that provided by endogenous soil N sources.

Study B: N Sources Comparison

Biomass yields of shoot and roots changed significantly with N source and N rate (Table 1). Combined data indicated that shoots had 70% more biomass than roots. Biomass yields at each N rate for urea (U) were dramatically lower than those observed with ammonium sulfate (AS). Since this study was carried out using undrained pots, a lower U response could be related to N losses in a saturated, anoxic zone through denitrification. Hauck (1981) estimated that 30% of added N fertilizer could be lost by denitrification, especially in saturated conditions. Ammonium sulfate applications increased shoot biomass up to a rate of 90 kg N ha^{-1} while shoot biomass with U applications increased up to a rate of 180 kg N ha^{-1}. Root biomass for the U application followed the same pattern as shoot biomass; and again, AS produced much more biomass than an equivalent rate of U.

Nitrogen sources had an effect on tiller density and height that mirrored shoot biomass data (Figure 6). Tiller density was 35% higher greater overall with AS application. There were consistently more tillers at any rate with AS than with U. Within each N source, no differences in tiller density above 180 kg N ha^{-1}, but a plateau was reached at 116 kg N ha^{-1} for U and 85 kg N ha-1 for AS. Height plateaued at 60 kg AS ha^{-1}, while no height increased was observed past 150 kg U ha^{-1} (Figure 7). No height differences were observed between the 45 and 90 kg U ha^{-1}. Both biomass and morphological parameters seem to suggest AS is a much better N source than U in the soiless substrate of this experiment.

Plant components differed in N concentrations depending on N source and rate of application (Table 2). Nitrogen concentration in roots averaged 13% higher under U application than AS and 34% higher in shoots. Increases in N concentrations were observed up to 270 kg N ha^{-1} with AS. Based on study A (Figure 3), we would expect a lower maximum value. The 3% N value is very high for switchgrass. Urea applications had no effect on tissue N levels beyond the 90 kg U ha^{-1}. Roots showed increases in N concentration with the highest AS application. No increases in root N concentration were observed past 90 kg U ha^{-1}.

Nitrogen content followed the expected pattern, given the yields and N concentrations seen. Differences due to N source and application rate were large (Table 3). Switchgrass N content was many-fold higher with AS application. Nitrogen content in the shoots was ~5X higher with AS application. Ammonium sulfate increased shoot N content at the highest rate of application. No differences in shoot N content were observed with U application past the 180 kg U ha^{-1} rate. In the roots, N content plateaued at 180 kg N ha^{-1} under both N sources. Either major losses of N from U or U toxicity would seem to be at play.

Nutrient-use efficiency, ANR and PFP showed no

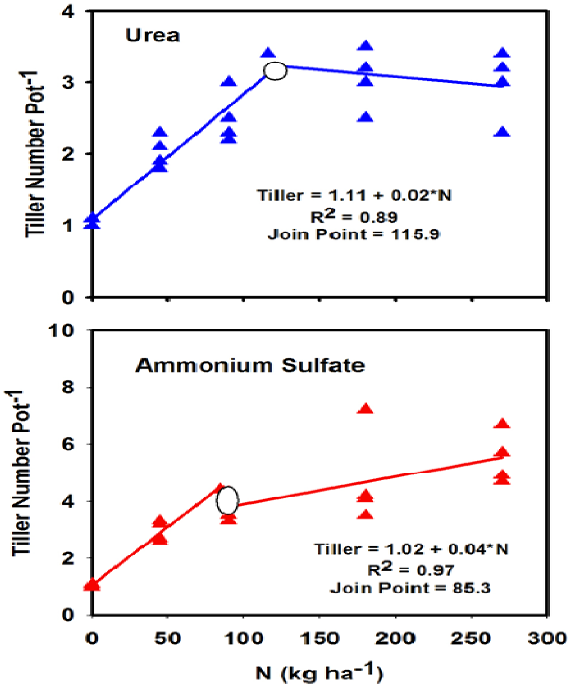

Figure 6. Changes in tiller number with N applied from two sources to substrate grown switchgrass seedlings in the greenhouse (Study B).

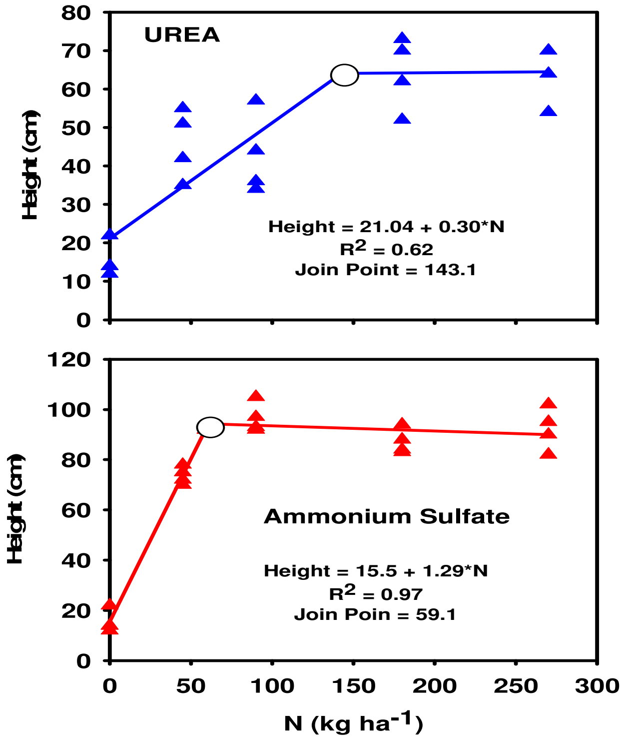

Figure 7. Changes in height with N applied from two sources to substrate grown switchgrass seedlings in the greenhouse (Study B).

Table 2. Changes in greenhouse-grown switchgrass root and shoot N concentrations with N applied from two sources.

		N (kg ha^{-1})					
Part	**Source**	**0**	**45**	**90**	**180**	**270**	**$LSD_{0.05}$[3]**
		----------------- N Conc. (%) --------------					
Shoot	AS[1]	1.44	1.44	1.90	2.68	3.09	0.17
	Urea	1.44	2.00	2.63	2.71	2.66	0.41
	$LSD_{0.05}$[2]	--	ns	ns	ns	0.21	--
Root	AS	0.91	0.67	1.01	1.65	2.09	0.26
	Urea	0.91	1.08	1.91	2.09	2.18	0.44
	$LSD_{0.05}$[2]	--	ns	0.84	ns	ns	--
	$LSD_{0.05}$[5]	--	0.16	0.17	0.23	0.42	--
	$LSD_{0.05}$[6]	--	0.23	0.47	0.19	0.10	--

[1] Ammonium sulfate
[2] LSD for comparison of N sources within N rate and part.
[3] LSD for comparison of N rates within part and N source
[4] LSD for comparison of N sources within N rate.
[5] LSD for comparison of parts within AS and N rate.
[6] LSD for comparison of parts within Urea and N rate.

Table 3. Changes in switchgrass root and shoot N content with applied N from two sources.

		N (kg ha^{-1})					
Part	**Source**	**0**	**45**	**90**	**180**	**270**	**$LSD_{0.05}$[3]**
		------------- N Content (mg pot^{-1}) -----------					
Shoot	AS[1]	2.3	126.2	290.6	418.4	532.6	82.1
	Urea	2.3	29.7	43.1	101.9	111.3	30.5
	$LSD_{0.05}$[2]	--	21.1	67.5	97.7	150.6	--
Root	AS	0.9	22.7	43.5	72.7	77.0	12.4
	Urea	0.9	6.1	11.2	26.5	27.4	4.7
	$LSD_{0.05}$[2]	--	7.8	12.7	26.9	26.7	--
Total	AS	3.2	148.9	334.1	491.0	609.6	87.1
	Urea	3.2	35.8	54.4	128.4	138.7	33.9
	$LSD_{0.05}$[2]	--	28.8	74.8	121.1	163.7	--
	$LSD_{0.05}$[5]	--	8.4	57.6	53.4	172.0	--
	$LSD_{0.05}$[6]	--	12.5	30.3	38.8	33.4	--

[1] Ammonium sulfate
[2] LSD for comparison of N sources within N rate and part.
[3] LSD for comparison of N rates within part and N source
[4] LSD for comparison of N sources within N rate.
[5] LSD for comparison of parts within AS and N rate.
[6] LSD for comparison of parts within Urea and N rate.

differences between N sources. Mean NUE, ANR and PFP were ~16.6 g g^{-1}, 7.6%, and 8 g g^{-1}, respectively. Significant differences were observed between N rates (Figure 8). All N-use factors were negatively correlated with increase in N application rates [NUE ($r = -0.44$, $P < 0.001$), ANR ($r = -0.67$, $P < 0.001$), and PFP ($r = -0.71$, $P < 0.001$)]. Nutrient use-efficiency was highly correlated with ANR ($r = 0.85$, $P < 0.001$) and PFP ($r = 0.84$, $P < 0.001$). Apparent N recovery was highly correlate also with PFP ($r = 0.99$, $P < 0.001$). N-use parameters in study B were comparable to those values observed in study A, when averaged over N source, except PFP. Partial factor productivity was ~4X lower in study B. These lower PFP values are directly related to the lower yields with U.

Correlations among N applied and Yield Components

Several parameters examine were very highly correlated with N rates (Table 1). Correlation of each N source with

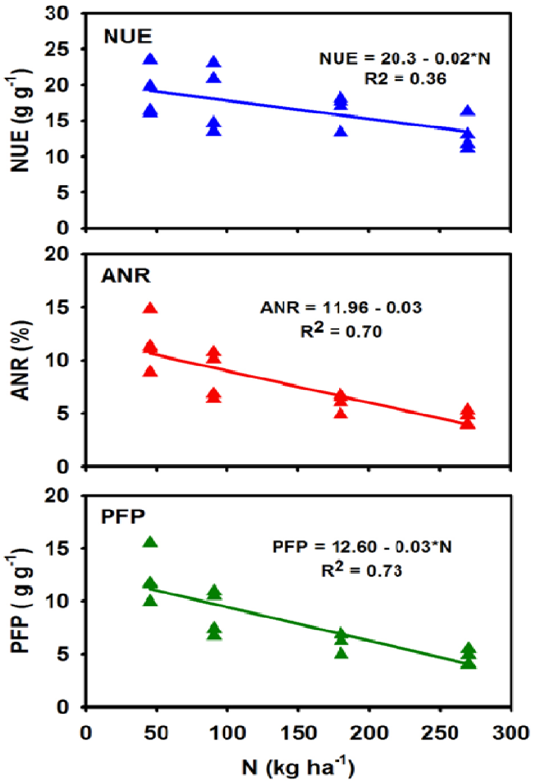

Figure 8. Effect of N rate on N-use efficiency (NUE), apparent N recovery (ANR), and partial factor productivity (PFP) of substrate grown switchgrass seedlings (Study B).

Table 4. Correlations between N rate and switchgrass yield components for greenhouse-grown switchgrass in two studies (A and B) and two N sources (urea and ammonium sulfate).

	N Rate		
		Study B	
	Study A	**Urea**	**Ammonium Sulfate**
N Rate	--	--	--
Yield	0.92*	0.87*	0.80*
% N	0.94	0.72*	0.97*
N Content	0.99*	0.90*	0.94*
Tiller	0.94*	0.81*	0.84*
Height	0.76*	0.81*	0.67*

*Significant at P = 0.05.

the different yield variables measure in switchgrass showed that biomass yield was better correlated with AS in study A, but yet be better correlated with U in study B (Table 4). Nitrogen concentration was highly correlated for the AS in both studies. These are shown by the higher values in the different switchgrass components. Also, N content had a high correlation with N rates in both studies. Nitrogen rate also had a great influence on tiller development. A reason to why the increase in biomass was correlated with increases in tiller number. Nitrogen concentration had a somewhat lower correlation with N rate. A lower correlation between height and AS was a reflection of the linear plateau reached at lower N rates in both studies (Figures 2 and 7). The data in both studies showed very high correlations with yield components, but greater influences were not reflected in the yields as expected. This means that although switchgrass has the capability to absorbed N in large quantities, the utilization efficiency of such available N is minimal.

CONCLUSIONS

Management of switchgrass greatly depends on fertilization strategies. Our data showed a lower response of switchgrass to urea applications. If urea will the preferred choice of fertilizer, it will be necessary to determine how it might affect plant growth. This poor response could have been related to some unknown form of toxicity or higher rates of N loss from urea, via denitrification or volatilization.

While our results suggested that, under well-defined substrate conditions, seedling switchgrass can respond to up to 200 kg N ha^{-1}. Recommendations of 45 to 100 kg N ha^{-1} yr^{-1} are usually made under field conditions (Wolf and Fiske, 1994). This is an indication that soil N dynamics play an important role in switchgrass N uptake and utilization. Microbial symbioses, N mineralization, and internal N "reserves" translocated between roots and shoots throughout the season could explain why switchgrass is often less N-responsive in a field setting. Taking into consideration the N cycle as a dynamic model to better understand switchgrass nutrient use efficiency will be important. Further studies that incorporate both approaches (greenhouse and field settings) will be beneficial in developing more precise recommendations.

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