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Nitrogen Rate and Application Timing Affect 'Beauregard' Sweetpotato Yield and Quality

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***Abstract.* Previous work suggests that 'Beauregard' sweetpotato [*Ipomoea batatas* (L.) Lam.] has a much lower N requirement than other common cultivars. Over the past 10 years, 'Beauregard' has become the premier sweetpotato cultivar grown in Virginia; however, N fertilizer recommendations have not been reassessed to consider the potentially lower N requirement of 'Beauregard'. The objectives of this study were to evaluate the effects of N rate and application timing on root yield, quality, and N use efficiency for 'Beauregard' sweetpotato production in Virginia. A field study was conducted each year from 2000 to 2002 at the Eastern Shore Agricultural Research and Extension Center, Painter, Va. Nitrogen fertilizer was applied at rates of 28, 56, and 84 kg·ha^{-1} either before transplanting, 2 to 3 weeks after transplanting (WAT), or 4 to 5 WAT. A check treatment that received no N fertilizer was also included. Optimum N rates varied annually; under normal precipitation, root yield was greatest at the 28-kg·ha^{-1} rate, while 56 kg·ha^{-1} was required for maximum yield in wet conditions. Of note is that this range of rates is considerably lower than the current N recommendation for Virginia sweetpotato production (56 to 84 kg·ha^{-1}). Delaying N application until 2 to 3 WAT further increased marketable root yield compared with applying N before transplanting or 4 to 5 WAT. Crude protein and N uptake increased with increasing N rate up to 84 kg·ha^{-1}; however, N use efficiency was highest (67%) when 28 kg·ha^{-1} was applied 2 to 3 WAT.**

Optimizing N fertilizer applications is critical for commercial sweetpotato [*Ipomoea batatas* (L.) Lam.] production. While some level of N fertilization is almost always necessary to obtain optimum root yield (Walker and Woodson, 1987) and protein concentration (Purcell et al., 1982), excessive N can reduce yield (Villagarcia et al., 1998). Extreme moisture at high N fertility levels has also resulted in decreased root yield and quality (Constantin et al., 1974). Variations in soil and climatic characteristics and genotypic differences in N uptake and utilization efficiencies make identifying this optimum N balance extremely complicated.

Sweetpotato yield responses to N applications vary considerably and are often inconsistent or contradictory (Bellinder and Morse, 1982; Mascianica, et al., 1985). Large field-to-field differences in crude protein content and other quality factors of sweetpotato also exist (Purcell et al., 1978; Constantin et al., 1984). The difficulty in determining optimum N rates for sweetpotato production often results in low N use efficiency (NUE; percentage of applied N removed in the harvested portion of the crop), which can lead to excess fertilizer N remaining in the environment and having the potential to impact water quality (Marti and Mills, 2002). This fact combined with the cost of N fertilizer dictate a necessity for high NUE.

Villagarcia et al. (1998) alluded to the importance of NUE in sweetpotato production when they defined the ideal sweetpotato plant as "one that is efficient in acquisition of N and its use to maintain photosynthetic activity when the substrate supply of N is low, yet one that retains its capacity to initiate storage roots and partition photoassimilates to them when substrate supply is high." It is documented that N uptake and assimilation rates differ among sweetpotato cultivars (Walker and Woodson, 1987; Villagarcia et al., 1998; Hill et al., 1990); however, these differences often do not translate into differences in NUE (Marti and Mills, 2002). Hill et al. (1990) identified several sweetpotato cultivars that were capable of producing high yields without N fertilizer additions on N-deficient soils. One cultivar that may possess this trait and subsequently higher NUE is 'Beauregard', which was released by the Louisiana Agricultural Experiment Station in 1987 (Rolston et al., 1987).

'Beauregard' is one of the predominant sweetpotato cultivars grown in the mid-Atlantic U.S. In North Carolina, which is ranked number one in sweetpotato production (Virginia Agricultural Statistics Service, 2002), acreage planted to 'Beauregard' has increased steadily over the past 10 years (Schultheis et al., 1999), while nearly 100% of the orange-flesh acreage in Virginia is planted to 'Beauregard' (S.B. Sterrett, personal communication). Research from North Carolina suggests that 'Beauregard' has a much lower N requirement than other common cultivars (Peet, 2003) and that lower N application rates can be used for commercial production of 'Beauregard' (56 kg·ha^{-1} compared with 90 to 108 kg·ha^{-1}; Jester, 1995). These lower N rates can be applied without a reduction in root yield (Jester, 1995), which would result in higher NUE for 'Beauregard' compared with other cultivars. In the North Carolina studies, N at 56 kg·ha^{-1} was adequate for optimum yield even in years with excessive rainfall, suggesting that the optimum N rate for 'Beauregard' production might actually be lower; however, N application rates below 56 kg·ha^{-1} were not evaluated. Cultural practice guidelines for the mid-Atlantic region also indicate that 'Beauregard' stand establishment is more uniform and the total marketable yield is highest when N applications are delayed 3 to 5 weeks after transplanting (Jester, 1995; Tuckey, 2001).

Current Virginia recommendations suggest applying N at 28 kg·ha^{-1} at transplanting and another 28 to 56 kg·ha^{-1} when vines begin to proliferate (about 4 to 5 weeks after transplanting) (Alexander et al., 2003). No adjustments have been made to the recommendations since 'Beauregard' has become the premier cultivar in Virginia. Personal communication with Virginia sweetpotato growers indicates that most are still applying N at rates of approximately 56 to 67 kg·ha^{-1}. It is not unreasonable to assume that optimum N fertilizer strategies for 'Beauregard' sweetpotato production in Virginia would be similar to those in North Carolina and that the current N fertilizer recommendations in Virginia may need to be reassessed. Therefore, the objectives of this study were to 1) identify the optimum N rate and time of application for 'Beauregard' sweetpotato production in Virginia and 2) determine the effect of N rate and timing on root quality characteristics and NUE.

Materials and Methods

A field experiment was conducted each year from 2000 to 2002 at the Eastern Shore

Table 1. Annual and 60-year average growing season precipitation (including irrigation), Painter, Va., 2000 to 2002.

	Precipitation (mm)			
Month	2000	2001	2002	60-year avg
June	90.9	134.1	54.6	85.1
July	210.6	236.0	170.7^{z}	110.5
August	168.7	51.8	69.3	105.2
September	122.2	58.4	53.3	90.2
Total	592.4	480.3	322.5	391.0

^{z}12.7 mm applied via irrigation on 16 July and again on 17 July.

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Table 2. Cultural practice dates for 'Beauregard' sweetpotato N management study, Painter, Va., 2000 through 2002; numbers in parenthesis indicate days after transplanting.

Year	Transplanted	2 to 3 WAT[z]	4 to 5 WAT[z]	Harvested
2000	16 June	10 July (24)	25 July (39)	16 Oct (115)
2001	20 June	10 July (20)	23 July (33)	17 Oct (119)
2002	5 June	24 June (19)	8 July (33)	2 Oct (119)

[z] WAT = weeks after transplanting; sidedress fertilizer application dates.

Agricultural Research and Extension Center, Painter, Va., on a Bojac sandy loam (mixed, thermic Typic Hapludult). Annual growing season rainfall at the site is reported in Table 1. The experimental design was a randomized complete block with four replications. Plot size consisted of four 7.6-m rows with 0.9 m between rows and 30.5-cm plant spacing. Nitrogen fertilizer treatments consisted of three rates (28, 56, and 84 kg·ha^{-1}) applied as ammonium nitrate (34–0–0) either before transplanting, 2 to 3 weeks after transplanting (WAT), or 4 to 5 WAT (Table 2). A 56-kg·ha^{-1} rate was also split-applied using two 28-kg·ha^{-1} increments applied either before transplanting and 2 to 3 WAT, before transplanting and 4 to 5 WAT, or 2 to 3 WAT and 4 to 5 WAT. A check plot that received no N fertilizer was also included. Additional nutrients applied each year to the experimental area included P_2O_5 at 56 kg·ha^{-1} and K_2O at 112 kg·ha^{-1} as triple superphosphate (0–46–0) and potassium chloride (0–0–60), respectively. All fertilizer sources were broadcast-applied using a ground-driven, drop-type dry fertilizer spreader and incorporated into the upper 15 cm of soil.

Sweetpotato plants were established in early April each year in 39.4-m^2 plastic-covered, sand-filled, raised, wooden beds. Before planting, 4.5 kg of commercial fertilizer (10–10–10) was incorporated into each bed. About 68 kg 'Beauregard' seed was planted into each bed and watered as needed until field plot establishment. In June of each year, sprouts were pulled from the beds and transplanted into the plots using a 1-row mechanical transplanter (Table 2). Pesticides, cultivation, and irrigation were administered as needed throughout the duration of the study.

At harvest (115 to 119 d after transplanting; Table 2), roots were mechanically dug from the center two rows of each plot and collected by hand. Plot weight was recorded for yield determination. Harvested roots were graded according to USDA standards (U.S. Dept. of Agriculture, 1981), which included canner roots (diameter of 2.5 ≤ 4.4 cm), US #1 roots (diameter of 4.4 ≤ 8.9 cm), jumbo roots (diameter >8.9 cm), and cull roots (malformed or distorted roots). In 2000 and 2001, a subsample of US #1 grade roots was collected from each plot for determination of moisture and total N content. Subsamples were sliced horizontally, dried at 60 °C, and ground to pass a 150-µm sieve. Total N was determined using a CE Elantech NC 2100 automated dry combustion analyzer. Crude protein content was estimated by multiplying total N by 6.25 (Purcell et al., 1982). Nitrogen use efficiency for this study was calculated as [(N removed in harvested roots from the fertilized plot – N removed in the check plot)/N applied]. Statistical analyses of the data were performed using PROC GLM, linear and quadratic contrasts, and mean separation procedures outlined by SAS (SAS, 1990). Data were analyzed separately for each year with N rate and time of application as main factors. Optimum N rate for each application timing was determined by identifying the critical point (slope = 0) for the regression model $f(x) = \beta_0 + \beta_1x + \beta_2x^2$.

Results and Discussion

Root yield response to N rate. Nitrogen rate by time of application interactions were observed for the 2001 and 2002 yield data ($p < 0.05$); thus analyses of yield response to N rate were performed at each level of application timing. Similarly, the effect of application timing was analyzed using mean separation procedures at each level of N rate. Although no interaction was present in 2000, those data are also presented by N rate and application timing for consistency in reporting. Sweetpotato root yields increased as a result of N fertilization in each year of the study. Yield responses followed quadratic trends ($p < 0.05$) with optimum N rates ranging from 39 to 53 kg·ha^{-1} in 2000, 36 to 63 in 2001, and 19 to 40 kg·ha^{-1} in 2002, depending on time of application (Table 3). The variation in optimum N rate over the course of the study appeared to be related to growing season precipitation. In 2000, planting and early season conditions were normal; however, beginning shortly after the first sidedress N application and for the duration of the season, rainfall was about 64% greater than the 60-year average (Table 1). This weather pattern is reflected in the optimum N rate being lowest for preplant applications (39 kg·ha^{-1}; Table 3) and increasing during the period of heavy rainfall to 50 and 53 kg·ha^{-1} 2 to 3 and 4 to 5 WAT, respectively (Table 3). Although we have no substantiating data, it is possible that excessive rainfall could have resulted in some of the sidedress-applied N being leached out of the root zone. Our hypothesis that leaching of fertilizer N might have occurred in this study is supported by earlier work conducted at the same location that demonstrated greater sweetpotato yield responses to fertilizer N (higher optimum N rate) when growing season precipitation was excessive (60% higher than average; Bellinder and Morse, 1982).

An apparent relationship between precipitation and optimum N rate was observed again in 2001. In 2001, rainfall in June was 58% greater than normal (Table 1); however, most of the precipitation occurred before transplanting and only 38 mm was received during the first two weeks following transplanting. Rainfall remained moderate through the first sidedress application in July. The average rainfall distribution in the early to mid-growing season in 2001 resulted in optimum N rates being close to the optimum preplant rate in 2000 when precipitation was also normal (Table 3). However, during the first week following the second sidedress application, excessive rainfall was received (198 mm) and like 2000, the optimum N rate increased considerably (Table 3). No excessive rainfall events occurred in 2002 (Table 1); thus, optimum N rates were consistent across application timings and similar to those observed for applications made during periods of normal rainfall in previous years (Table 3). Further evidence for an N rate-rainfall relationship exists in the check (no N applied) yields for each year. Although initial soil inorganic N (NO_3-N + NH_4-N) levels (0 to 15 cm) were not different in any year (~7.5 mg·kg^{-1}; annual data not reported), in 2002, when precipitation was normal throughout the growing season, check yields were considerably higher than in the previous two years (Table 3), suggesting that available soil N at transplanting in 2000 and 2001 became unavailable at some point during the season.

Our data indicate that under typical conditions (times of normal, or average, precipitation), N at about 35 kg·ha^{-1} is adequate for optimum yield of 'Beauregard' sweetpotato. However, N at about 55 kg·ha^{-1} was required under exces-

Table 3. Marketable yield of 'Beauregard' sweetpotato roots following various N fertilizer rates and application timings, Painter, Va., 2000 through 2002.

		N (kg·ha^{-1})					Optimum N rate[y]
Year	Timing[z]	0	28	56	84	r^2	(kg·ha^{-1})
		Mg·ha^{-1}					
2000	Preplant	18.7	24.1	21.6	22.6	0.56	39
2000	2 to 3 WAT[x]	18.7	28.1	34.7	24.9	0.93	50
2000	4 to 5 WAT	18.7	21.6	22.0	22.1	0.97	53
LSD($p < 0.05$)		3.8	3.8	3.8			
2001	Preplant	13.6	20.2	18.5	16.9	0.85	36
2001	2 to 3 WAT	13.6	22.2	19.9	18.6	0.82	36
2001	4 to 5 WAT	13.6	18.9	21.7	20.1	0.91	63
LSD($p < 0.05$)		3.5	3.5	3.5			
2002	Preplant	31.5	33.0	31.4	29.7	0.91	19
2002	2 to 3 WAT	31.5	40.4	35.1	33.3	0.64	34
2002	4 to 5 WAT	31.5	35.1	34.8	32.8	0.97	40
LSD($p < 0.05$)			4.7	4.7	4.7		

[z] Timing indicates time of N application; before transplanting (preplant), 2 to 3 WAT, or 4 to 5 WAT.

[y] Optimum N rate for each application timing was determined by identifying the critical point (slope = 0) for the regression model $f(x) = \beta_0 + \beta_1x + \beta_2x^2$ ($p < 0.05$).

[x] WAT = weeks after transplanting.

sively wet conditions (Tables 1 and 3). These results support the conclusions of Jester (1995) who reported that N at 56 kg·ha^{-1} was adequate for 'Beauregard' production in North Carolina, even under excessive precipitation that resulted in fertilizer leaching. Our data also confirm Jester's supposition that N rates lower than 56 kg·ha^{-1} can be used for commercial 'Beauregard' production (Jester, 1995). Mulkey et al. (1993) reported optimum N rates for 'Beauregard' production to be closer to 50 kg·ha^{-1} under typical growing conditions in Louisiana. However, they produced considerably higher yields than in our study or the North Carolina study; thus removing more N and subsequently increasing the N demand. Therefore, the N requirement under normal conditions in Louisiana would be expected to be higher than that in Virginia or North Carolina.

Root yield response to timing of N application. Delaying N application until 2 to 3 WAT significantly increased marketable root yields in 2000 and 2002 (Table 3). Timing of N application did not significantly affect root yield in 2001. The lack of response to timing of N applications in 2001 may be due to an overall low-yielding year compared with other years in the study (Table 3), as well as historical yield averages for Virginia sweetpotato production (Virginia Agricultural Statistics Service, 2002). Several researchers have documented similar yield increases and greater crop uniformity when delaying N application to 'Beauregard' sweetpotato 3 to 5 WAT (Mulkey et al., 1993; Jester, 1995; Tuckey, 2001). Jester (1995) found that applying N 4 to 5 WAT resulted in the highest total marketable yields, while our results support those of Mulkey et al. (1993), in that total marketable yields were maximized when N was applied 3 to 4 WAT. In fact, our results are somewhat contradictory to those of Jester (1995) as delaying N application another two WAT resulted in root yields that were not different from those obtained using preplant N applications and lower than those using 2 to 3 WAT applications in 2000 and at the 28-kg·ha^{-1} rate in 2002 (Table 3). Excessive rainfall during the growing season, as discussed earlier, could explain this yield reduction in 2000; however 2002 was a normal year in terms of precipitation (Table 1) suggesting that 'Beauregard' plants are in fact more efficient at utilizing fertilizer N when it is applied 2 to 3 WAT compared with the same rate applied earlier or later in the season. Splitting the 56-kg·ha^{-1} rate into two 28-kg increments did not increase marketable root yield in any year over a single application of 56-kg·ha^{-1} 2 to 3 WAT (data not reported).

Table 4. USDA root grade distribution of 'Beauregard' sweetpotato as affected by N rate[z] and application timing, Painter, Va., 2000 through 2002.

	Weeks after transplanting [N (kg·ha^{-1})]			Grade[y] (%)			
Year	0	2 to 3	4 to 5	US #1	Canner	Jumbo	Cull[x]
2000	28	0	0	62	30	8	23
	0	56	0	63	27	10	22
	0	0	56	56	36	8	27
LSD($p < 0.05$)				7	5	4	4
2001	28	0	0	61	30	9	14
	0	28	0	66	30	4	13
	0	0	56	59	36	5	12
LSD($p < 0.05$)				7	6	6	3
2002	28	0	0	65	16	19	12
	0	28	0	66	17	17	12
	0	0	28	66	17	17	13
LSD($p < 0.05$)				7	4	7	2

[z] Nitrogen rate reported is the rate resulting in the highest marketable root yield at a given application time.

[y] Grade: USDA root grade: US #1, diameter of $4.4 \leq 8.9$ cm; canner, diameter of $2.5 \leq 4.4$ cm; jumbo, diameter >8.9 cm; cull, malformed or distorted roots.

[x] Cull = reported percentages of culled roots represent the nonmarketable portion of the total harvest; US #1, canner, and jumbo are expressed as percentages of marketable roots.

Table 5. Crude protein content, N uptake, and N use efficiency of 'Beauregard' sweetpotato roots as affected by various N rates and application timings, Painter, Va., 2000 to 2001.[z]

	2000			2001		
N rate (kg·ha^{-1})	Crude protein (g·kg^{-1})	N uptake (kg·ha^{-1})	NUE[y] (%)	Crude protein (g·kg^{-1})	N uptake (kg·ha^{-1})	NUE (%)
0	52.0	41.2	----	54.0	30.5	---
28	56.5	47.7	45.6	66.9	45.2	59.7
56	59.2	50.8	27.3	67.9	45.0	26.4
84	68.2	54.2	20.5	77.5	50.1	23.6
	L**	L**	L**	L**	L+	L**
56[x]	66.1	56.7	28.4	79.6	48.6	32.8
Time of application						
Preplant	59.7	42.5	19.4	70.9	42.9	18.9
2 to 3 WAT[w]	59.5	55.0	33.7	71.9	48.8	41.6
4 to 5 WAT	64.4	54.1	35.0	69.8	48.4	34.6
LSD($p < 0.05$)	6.6	10.5	11.3	7.3	10.9	15.1

[z] Reported means are averaged across application times or rates unless indicated otherwise.

[y] NUE = nitrogen use efficiency; [(N removed in the fertilized plot – N removed in the check plot)/N applied].

[x] Applied in two increments of 28 kg·ha^{-1} preplant and 2 to 3 weeks after transplanting.

[w] WAT = weeks after transplanting.

** Significant at $p < 0.01$; L = linear.

Root size distribution. Distributions of USDA root grades for each year of the study are reported in Table 4. Average size distribution for our 3-year study (65% US #1, 25% canner, and 10% jumbo) was similar to distributions reported for 'Beauregard' studies conducted in Louisiana (Mulkey et al., 1993; Rolston et al., 1987) and North Carolina (Jester, 1995; Schultheis et al., 1999). The main effect of N timing significantly affected root size distribution in 2000 and 2001 (Table 4). Delaying N application until 4 to 5 WAT reduced the percentage of US #1 grade roots and increased the percentage of canner roots (Table 4). In 2000, the percentage of culled roots also increased when N application was delayed 4 to 5 WAT compared with N applications made preplant or 2 to 3 WAT (Table 4). An effect of N timing on root size distribution was also reported by Mulkey et al. (1993) who found that delaying N application beyond 4 WAT increased canners 35% and decreased jumbo roots 50%. Conversely, Jester (1995) found no significant effect of N timing on root size distribution in North Carolina. It is noteworthy, however, that although the reported changes in root size distribution were not statistically significant, applying N at 5 WAT decreased the percentage of jumbo grade roots 78% compared to applying the same N rate 3 WAT (Jester, 1995). Jester (1995) and Mulkey et al. (1993) both reported N rate to have no effect on the relative size distribution of 'Beauregard' roots.

Researchers working with 'Jewel' sweetpotato similarly reported N rate to have no effect on root size distribution (Hammett et al., 1984). However, Constantin et al. (1984) found that increasing N rates from 0 to 50 kg·ha^{-1} linearly increased both total marketable yield and the percentage of US #1 grade roots for the sweetpotato cv. Centennial and Goldrush. Nitrogen rates >50 kg·ha^{-1} did not further increase yield or the percentage of US #1 roots (Constantin et al., 1984), suggesting that the optimum N rate for total yield can also result in the most economically desirable size distribution [i.e., high percentage of US #1 grade roots and a low percentage of canners and culls (Schultheis et al., 1999)]. Our data also demonstrated a relationship between optimum N rate and desirable size distributions. For example, in 2000, N applied preplant at 28 kg·ha^{-1} resulted in a root size distribution not different from that obtained when 56 kg·ha^{-1} was applied 2 to 3 WAT (Table 4). However, applying 56 kg·ha^{-1} preplant resulted in a lower percentage of US #1 roots (54%) and higher percentages of canners and culls (41 and 35%, respectively). Similarly, when only 28 kg·ha^{-1} was applied 2 to 3 WAT, the result was fewer jumbo roots (5%) and a higher percentage of canners (33%). This finding was observed again in 2001 with excessive N (56 kg·ha^{-1}) applied 2 to 3 WAT resulting in a higher percentage of canners (39%) and a lower percentage of US #1 roots (51%) compared with 28 kg·ha^{-1} applied at the same time. Splitting the 56-kg·ha^{-1} rate into two 28-kg·ha^{-1} increments did not affect root size distribution compared to a single application of 56 kg·ha^{-1} in any year (data not reported).

Root dry matter percentage, crude protein content, and N uptake. Root dry matter percentage was not affected by N rate or timing in any year of the study. Results from other studies have varied regarding the effect of N fertilizer on root dry matter percentage. Constantin et al. (1984) reported that dry matter content increased linearly (25.6% to 26.3%) with increasing N rates, while Hill et al. (1990) found no effect on root dry matter percentage following N additions. What is interesting about our results, is that while the effect of N rate on dry matter percentage was not statistically significant (similar to Hill et al., 1990), the increase in dry matter percentage with increasing increments of N (20.6% to 21.9%) was greater than that observed by Constantin et al. (1984) where the relationship was determined to be significant.

Researchers have also cited linear increases in crude protein content with increasing N rates for several cultivars including 'Centennial', 'Jewel', and 'Goldrush' (Purcell et al., 1982; Constantin et al., 1984). Our results with 'Beauregard' support those from other studies in that crude protein content increased with increasing N rates up to 84 kg·ha^{-1} ($p < 0.01$; Table 5). Average crude protein levels for 'Beauregard' (Table 5) were similar to those reported for other cultivars evaluated in the earlier studies (Constantin et al., 1984; Purcell et al., 1982). Delaying N application 2 to 3 or 4 to 5 WAT did not affect crude protein levels compared to applying N before transplanting (Table 5). However, splitting the 56-kg·ha^{-1} rate into two 28-kg increments applied at transplanting and 2 to 3 WAT increased crude protein compared with a single 56-kg·ha^{-1} application applied either before transplanting, 2 to 3 WAT, or 4 to 5 WAT in both 2000 and 2001 (Table 5).

Root N uptake also increased with increasing N rate in 2000 and 2001 ($p < 0.01$; Table 5). Timing of N application did not affect N uptake in 2001; however, in 2000, delaying N application 2 to 3 or 4 to 5 WAT increased N uptake compared with applying N before transplanting (Table 5). The occurrence of this response in 2000 and not in 2001 might be related to differences in rainfall patterns reported in Table 1 and discussed in previous sections. Hill et al. (1990) reported increased N uptake in total biomass following N fertilization of six cultivars; however, only two out of the six cultivars had significantly higher N uptake levels in storage roots compared with nonfertilized plants. One point they found particularly noteworthy in their work was that as much as 42 and 86 kg·ha^{-1} was taken up in the unfertilized and fertilized plots, respectively (Hill et al., 1990). Mineralization of soil organic matter appears to be a reasonable explanation for these results; however, since their trials were conducted on soils with very low inorganic N and organic C levels (11 mg·kg^{-1} and 7.5 g·kg^{-1}, respectively), they concluded that indigenous or residual soil N levels were not solely responsible for the amounts of N uptake measured in the plots (Hill et al., 1990). Hill et al. (1990) cited several possible explanations for such results including enhanced fibrous root exploration, symbiotic N_2 fixation, and other microbial N contributions, all of which can lead to certain genotypes being highly efficient in scavenging for scarce soil N reserves.

We observed N uptake responses similar to those reported by Hill et al. (1990) at the 0 and 28-kg·ha^{-1} rates in 2000 and 2001 (Table 5). In both years, root N uptake measured for the 0-N plots was considerably higher than what would have been expected given the low levels of residual soil N (~7.5 mg·kg^{-1}) and the 28-kg·ha^{-1} rate resulted in N uptake levels greater than the sum of inorganic soil N and applied fertilizer N (Table 5). Although root N uptake continued to increase beyond 28 kg·ha^{-1}, N uptake no longer equaled N applied at the higher rates (Table 5). Although unverified in our study, it is not unreasonable to conclude that 'Beauregard' may possess one or more of the attributes identified by Hill et al. (1990); thus partially explaining its lower fertilizer N requirement compared with other cultivars (Jester, 1994; Peet, 2003).

Nitrogen use efficiency. Nitrogen use efficiency of 'Beauregard' sweetpotato decreased with increasing N rate in 2000 and 2001 ($p < 0.01$; Table 5). Other researchers have calculated NUE differently, but the trends have been similar to those observed in our study (Marti and Mills, 2002; Villagarcia et al., 1998). A valid comparison of 'Beauregard' NUE with the cultivars used in the studies cited above is not possible due to different calculation methods; however, differences in NUE among cultivars have been cited. Villagarcia et al. (1998) noted that under nonlimiting N supplies, the NUE of MD810 and 'Jewel' were not different but under N-limiting conditions, the NUE of MD810 was almost twice that of 'Jewel'. Hill et al. (1990) did not evaluate NUE in their work; however, they reported all of the data necessary to calculate NUE using the method employed in our study.

Our calculated NUE values for the six cultivars evaluated by Hill et al. (1990) ranged from 20% to 88%. The cultivars with the highest N uptake levels relative to N applied (most efficient scavengers) had an average NUE of 55%. The NUE for the less efficient cultivars averaged 29%. In our dataset, only the 28-kg·ha^{-1} rate had N uptake levels that exceeded the soil-N and fertilizer-N contributions (Table 5). If we group our N-rate treatments in a categorically similar manner as the cultivars of Hill et al. (1990), we would identify 'Beauregard' as a highly efficient scavenger of N at low fertility levels (NUE of 53% at the 28-kg·ha^{-1} rate) and much less efficient at higher N fertility levels (NUE of 24% at N rates >28 kg·ha^{-1}).

Splitting the N into two applications did not affect NUE in either year; however, delaying a single N application 2 to 3 or 4 to 5 WAT significantly increased NUE compared with a preplant application (Table 5). Because there were no significant interactions present in the NUE analyses, data were not reported by rate and timing. Nonetheless, if we consider our most efficient N rate (28 kg·ha^{-1}) applied at the most efficient time (2 to 3 WAT); the NUE values for 'Beauregard' in 2000 and 2001 were 59% and 75%, respectively.

Our work clearly establishes that 'Beauregard' is more productive (Table 3) and more efficient (Table 5) at N rates considerably lower than those currently recommended for Virginia sweetpotato production (Alexander et al., 2003). Applying the appropriate N rate (~35 kg·ha^{-1}) 2 to 3 WAT maximized root yield, percentage of US #1 grade roots, and NUE.

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