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Nitrogen Application Increases Yield and Early Dry Matter Accumulation in Late-Planted Soybean

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ABSTRACT

In double-cropped soybean [*Glycine max* (L.) Merr.] planting is delayed, with a corresponding decrease in yield associated with photoperiod-induced early flowering and reduced accumulation of dry matter during the vegetative growth period. Application of nitrogen (N) has been shown to improve yield of late-planted soybean. We conducted a field study to determine the optimum economic rate of N that would stimulate early dry matter accumulation, and thus yield, in late-planted soybean. The effects of three planting dates (mid-June, late-June, and mid-July), two MG VIII cultivars (Kuell and Prichard), and five N rates (0, 25, 50, 75, and 100 kg ha^{-1}) were studied for 2 yr at three Alabama locations (Fairhope, Shorter, and Crossville). Nitrogen application of 60 to 70 kg ha^{-1} maximized yield and R1 dry matter accumulation. However, N reduced nodule number and mass, but had no effect on R1 plant height, mature plant height, or seed quality, protein and oil content. Yield was reduced linearly by later planting, but there was no interaction between N rate and planting date for yield. Kuell was taller at maturity and had more R1 dry matter than Prichard, but Kuell yielded more than Prichard in only one environment and there was no cultivar × N rate interaction for yield. At current prices for N and soybean, we concluded that N can be a viable input for double-cropped soybean at an optimal economic rate of 59 kg ha^{-1}.

Approximately one-half of the soybean crop grown in the southeastern USA is grown in a double-crop system following a cool-season small grain crop, or following maize (*Zea mays* L.) in the southernmost latitudes (Wallace et al., 1992). Thus, soybean planting is delayed past dates recommended for optimum yield. Yield is reduced in these late-planted systems primarily because of a shortened period of vegetative growth and earlier flowering caused by a combination of warm temperatures and shortened time to photoperiod-induced flowering (Board and Hall, 1984). Research on the relationship between yield and variables related to plant size in late-planted soybean systems has been mixed. Dry matter production at the R5 and R7 developmental stages (Fehr and Caviness, 1977) has been shown to affect yield of late-planted soybean (Board et al., 1996). Carter and Boerma (1979) also found a positive relationship between both plant height at flowering and mature plant height, and yield in late-planted soybean. Egli et al. (1987) suggested a minimum vegetative mass of 500 g m^{-2} dry matter at beginning pod fill (R5 stage) for maximum seed yield in late-planted soybean cropping systems. Starling et al. (1998) observed a significant positive relationship between dry matter accumulation at R1 and yield of late-planted soybean for two genotypes but not another.

Various means have been proposed to improve dry matter accumulation, and thus yield, in late-planted soybean. Using near-isolines, Pfeiffer and Harris (1990) investigated several genes affecting growth and vegetative weight but found none of the genes actually increased vegetative plant weight at the R5 developmental stage compared to the control, and thus, there was no relationship between yield in late-planted soybean and genes promoting greater vegetative growth. Pfeiffer (2000) also proposed selecting soybean genotypes with increased full-season plant height as a method of indirect selection for increased dry matter production at late planting dates. However, selection of tall lines did not improve performance in the late-planted system. Development of genotypes with indeterminate stem termination has been proposed for increasing height of late-planted soybean (Boerma et al., 1982), but success of this strategy has also been limited (Ouattara and Weaver, 1994; Weaver et al., 1991). Starling et al. (1998) proposed an at-planting application of N could be used to promote early vegetative growth in late-planted systems. Broadcast N (50 kg ha^{-1}) applied at planting increased R1 dry matter accumulation of determinate and indeterminate stem-termination type near-isolines by 25%, but had no effect on R1 dry matter accumulation of determinate 'Cook'. However, seed yield of all three genotypes was increased by N application, on average by at least 8% (Starling et al., 1998). Greenhouse studies have also shown an increase in early soybean plant growth as a result of applied N (Eaglesham et al., 1983). However, results from field studies on the effect of N fertilizer on soybean yield have been mixed. Many studies have shown an increase in yield and associated dry matter accumulation as a result of N application to soybean (Afza et al., 1987; Al-Ithawi et al., 1980; Ham et al., 1975; Sorensen and Penas, 1978; Touchton and Rickerl, 1986; Wood et al., 1993), while others have shown no such response (Beard and Hoover, 1971; Deibert et al., 1979; Welch et al., 1973) or a reduction in yield and dry matter caused by N application (Peterson and Varvel (1989). None of these studies was conducted in a late-planted production system.

The objectives of our research were threefold: (i) to evaluate the response of variables related to early vegetative plant growth (dry matter accumulation and plant height at the R1 developmental stage) and seed yield to N application rate, (ii) evaluate the effect of N application on variables related to N metabolism in soybean (plant N concentration, nodule number, and seed traits), and (iii) determine the optimum N rate for production of late-planted soybean in the Deep South.

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Table 1. Total monthly rainfall and average soil temperature at 10-cm depth.

Environment	June	July	August	September	October	November	June	July	August	September	October	November
	mm						°C					
SMREC† 2000	103	17	37	85	6	194	25	28	28	24	19	12
SMREC 2001	85	83	96	81	56	107	26	28	27	21	17	14
EVS 2000	33	46	52	99	13	‡	32	35	33	28	23	‡
EVS 2001	155	66	65	37	30	77	29	32	33	30	22	18
GCREC 2000	154	92	73	215	9	187	30	38	31	28	23	17
GCREC 2001	356	248	220	111	90	42	29	29	29	26	19	20

† SMREC = Sand Mountain Research and Extension Center, Crossville, AL; EVS = E.V. Smith Research Center, Shorter, AL; GCREC = Gulf Coast Research and Extension Center, Fairhope, AL.
‡ Plots were harvested before November at this location.

MATERIALS AND METHODS

Field experiments were conducted in 2000 and 2001 in six Alabama environments: the Sand Mountain Research and Extension Center (SMREC, Crossville, AL, 34°28′ N), the E.V. Smith Field Crops Unit (EVS, Shorter, AL, 32°22′ N), and the Gulf Coast Research and Extension Center (GCREC, Fairhope, AL, 30°33′ N). Soils at these locations were Hartsells fine sandy loam (fine-loamy, siliceous, subactive, thermic Typic Hapludults) at SMREC, Norfolk fine sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults) at EVS, and Malbis fine sandy loam (fine-loamy, siliceous, subactive, thermic Plinthic Paleudults) at GCREC. Rainfall and soil temperature data for the soybean growing season were collected for each environment (Table 1).

The experimental design at each location–year combination was a randomized complete block with a $3 \times 5 \times 2$ treatment structure with four replications and split plots. Three planting dates were whole plots, with five N rates and two maturity group (MG) VIII soybean cultivars randomized within whole plots. The target for the first planting date was early June, followed by the second and third planting dates at approximately 3-wk intervals. These correspond to the range of planting dates likely to be encountered in a small grain-soybean or maize-soybean double-crop system. Because of weather and logistics, actual planting dates deviated somewhat from the target dates (Table 2). Nitrogen rates were 0, 25, 50, 75, and 100 kg N ha^{-1} broadcast applied as ammonium nitrate immediately after planting. Soybean cultivars Kuell (Weaver et al., 2000) and Prichard (Boerma et al., 2001) were selected primarily on differences in mature plant height. Compared to Cook (Boerma et al., 1992), a standard MG VIII cultivar, Kuell is 8 cm taller and Prichard is 3 cm shorter. Kuell was released specifically because of superior performance in late-planted environments.

Land preparation consisted of disk harrowing followed by rotary tilling to prepare the seedbed. Previous crops were either cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.) or maize depending on location (Table 2). Plots were planted with a grain drill, with 14 rows and 15 cm between rows. Plot length was 7 m. Plots were seeded at a rate of 20 seeds m^{-1} of row. Fertilizer was applied according to Auburn University Soil Testing Laboratory recommendations (Table 2). All environments received 1.8 L ha^{-1} metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide] applied pre-emergence after planting. When needed, supplemental irrigation was applied at EVS. Because of dry weather, the third planting date at SMREC and the second planting date at GCREC in 2000 failed to achieve a stand, and no data were collected from these treatments. Immediately before N application and planting, 30 random soil cores (2.5-cm diameter; 0- to 15-cm depth) were collected in each replication of planting date main plots and composited to determine nitrate N (NO_3–N) concentrations. Soil NO_3–N concentrations were determined from 2 *M* potassium chloride extracts analyzed by the microplate method (Sims et al., 1995).

Dry matter yield at the R1 developmental stage was determined by harvesting, drying and weighing above-ground samples from 1 m of an inner border row, not in the intended harvest area. Nitrogen concentration of the dried whole-plant soybean tissue was determined with a LECO CHN-600 analyzer (LECO Corp., St. Joseph, MO). Also at R1, plant height was measured and root samples were taken with an 8-cm diam core barrel to a depth of 20 cm. Samples were washed with a hydropneumatic root washer to remove soil. Nodules were counted, and nodule dry weight data collected.

At maturity, plots were end-trimmed to 5.0-m length and 10 bordered rows (1.5-m width) harvested with a small plot combine. Lodging (1-to-5 scale, 1 = upright and 5 = prostrate) and mature plant height were recorded. Seed oil and protein content (dry matter basis) were determined by near-infrared analysis at the National Center for Agricultural Utilization Research, Peoria, IL (Nelson et al., 1988). Seed weight and quality was determined from a 100-seed sample. Seed quality is determined by a variety of environmental and disease factors, and was rated on a scale of 1 (good quality) to 5 (very poor quality).

Data were analyzed by the PROC MIXED procedure of SAS (Littell et al., 1996) as a randomized complete block design with a split plot restriction on randomization. All factors in the experiment were considered fixed, except blocks

Table 2. Locations, years, previous crop, fertilizer applied, and planting dates for each environment.

Environments	Previous crop†	P	K	First planting	Second planting	Third planting
		kg ha^{-1}				
SMREC‡ 2000	cotton	29	56	May 31	June 21	July 11§
SMREC 2001	wheat	40	73	June 12	July 12	August 2
EVS 2000	cotton	0	0	June 1	June 22	July 12
EVS 2001	cotton	0	0	June 15	July 10	July 27
GCREC 2000	maize	19	37	June 8	July 6§	July 27
GCREC 2001	cotton	19	37	June 7	June 28	August 3

† Previous crop was grown the summer or winter before, and not as a previous crop the same year in a double-cropping system.
‡ SMREC = Sand Mountain Research and Extension Center, Crossville, AL; EVS = E.V. Smith Research Center, Shorter, AL; GCREC = Gulf Coast Research and Extension Center, Fairhope, AL.
§ Test was planted, but stand failed to emerge sufficiently due to dry weather.

and environments, which were random. All interactions involving blocks and environments were random. Interactions were considered an important source of variation if the $P > F$ was ≤ 0.10. Environments SMREC 2000 and GCREC 2000 were excluded from the analysis because one of the planting dates (third planting date at SMREC 2000 and second planting date at GCREC 2000) could not be established in these locations due to inclement weather. The intended orthogonal structure between location and year was thus destroyed and the remaining locations and/or years combined into the single source "environment" in the ANOVA.

RESULTS AND DISCUSSION

R1 Stage

Dry matter accumulation at the R1 stage was significantly increased by N application at all three planting dates (Table 3). Planting date also affected R1 dry matter, with an average decrease of 193 kg ha^{-1} for every 3-wk delay in planting. There was an interaction between planting date and N application rate for R1 dry matter, but this was due primarily to the differences in magnitude of R1 dry matter response to N at the different planting dates. Even though N application consistently increased R1 dry matter, the response tended to get smaller as planting date was delayed from early June to mid July or later. Up to an N application rate of 75 kg ha^{-1}, every 25 kg ha^{-1} increment of applied N increased R1 dry matter yield by an average of 77 kg ha^{-1} at the first planting date, 43 kg ha^{-1} at the second planting date and 35 kg ha^{-1} at the third planting date. There was also a significant cultivar × N rate interaction ($P = 0.04$) for R1 dry matter due to differences in magnitude of the response to N rate. However, rankings were consistent; Kuell produced more R1 dry matter than Prichard at every N rate. Thus, data for R1 dry matter yield were averaged over cultivars (Table 3). A second order polynomial was fitted to R1 dry matter yield (Fig. 1). Getting the first differential of this equation and solving for zero the N rate for maximal R1 biomass was estimated at 63 kg ha^{-1}.

Plant N concentration also was increased by N application but in a linear fashion (Fig. 1). It follows that since R1 biomass and plant N concentration increased with N application rate then R1 N uptake (or fixation) also increased with N application rate as well. Applied N had no effect ($P = 0.13$) on plant height at R1 (data not shown), in contrast to the findings of Starling et al. (1998) who found that N at a rate of 50 kg ha^{-1} increased R1 plant height of late-planted soybean by an average of 3 cm. Thus, while dry matter increased in response to N, plant height did not. As expected, Kuell was taller than Prichard at both developmental stages (8.6 cm taller at R1 and 4.2 cm taller at R8). While application of N did not change plant height, the goal of promotion of early dry matter accumulation by application of N was accomplished regardless of cultivar, planting date, and environment.

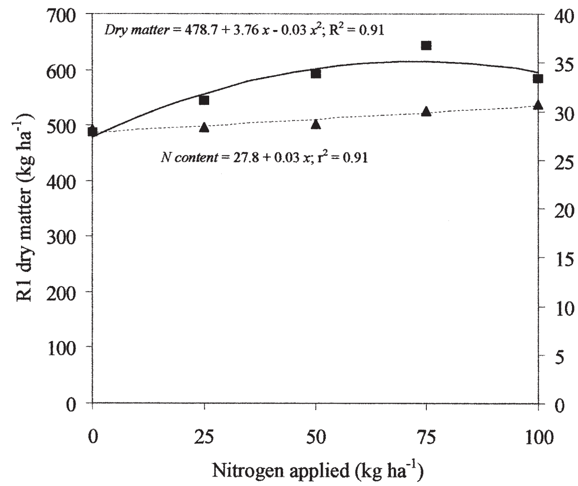

Fig. 1. Response of R1 dry matter and N content to application of N, averaged over planting dates, environments, and cultivars.

Applied N also affected nodule numbers and mass at the R1 stage. Nodule number was decreased (Fig. 2) by applied N, but the decrease was more pronounced at the second planting date, resulting in a significant planting date × N rate interaction. There was a significant cultivar × N rate interaction ($P = 0.03$) for nodule number, yet dummy variable regression (Draper and Smith, 1981) indicated that a common linear regression (nodule number $= 23.4 - 0.14 \times$ N rate; $r^2 = 0.82$; $P < 0.01$) best described the response; neither a dummy variable representing cultivar nor a polynomial model improved the model fit. Results for nodule mass were similar: Nodule mass was decreased by applied N, with a greater rate of reduction at the second planting date, resulting in a significant planting date × N rate interaction (data not shown). Previous research has shown that nodule number and mass decrease as soil NO_3–N concentrations or N application rates increase (Starling et al., 1998).

Table 3. R1 dry matter, seed yield and lodging for three planting dates and five N rates, averaged over two cultivars and four environments.

	R1 dry matter			Seed yield			Lodging		
N rate	Planting date 1	Planting date 2	Planting date 3	Planting date 1	Planting date 2	Planting date 3	Planting date 1	Planting date 2	Planting date 3
	kg ha^{-1}			Mg ha^{-1}			Score		
0	630	528	303	3.1	2.8	2.2	2.3	2.2	1.5
25	705	577	348	3.5	3.1	2.6	2.6	2.0	1.3
50	801	608	366	3.7	3.3	2.6	2.7	2.4	1.5
75	860	657	409	4.0	3.6	2.8	3.2	2.7	1.4
100	711	685	357	3.6	3.3	2.6	3.7	3.2	1.4
Mean	742	611	357	3.6	3.2	2.6	2.9	2.5	1.4
LSD(0.05)†	93			0.3			0.3		

† LSD values are for comparison of any two numbers in the same column for each variable measured.

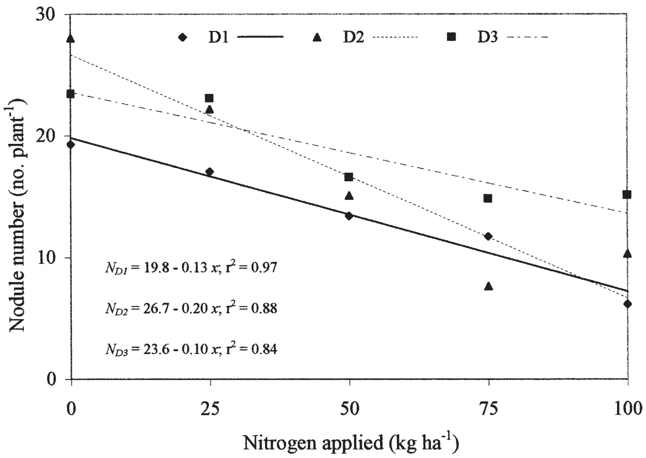

Fig. 2. Response of nodule number at the R1 developmental stage to applied N at three planting dates averaged over environments and cultivars. D1 = planting date 1, D2 = planting date 2, and D3 = planting date 3.

R8 Stage

Nitrogen application increased seed yield, with a steady yield increase up to an N rate of 75 kg ha^{-1}, regardless of planting date, cultivar, or environment (Table 3 and Fig. 3). Seed yield was increased very consistently over planting dates, with an increase of 29% at the first and second planting date, and 27% at the third, before showing a slight decrease at the N rate of 100 kg ha^{-1} for all three planting dates. The second order polynomial response curve (Fig. 3), indicated that 69 kg N ha^{-1} produced the maximum seed yield, which was close to the N rate for maximum R1 dry matter yield (63 kg N ha^{-1}). To calculate the optimum rate from an economic standpoint, we set the first derivative of the second order polynomial net return to N applied as a function of N rate to zero and solved for N rate. Assuming a price of \$300 Mg^{-1} of soybean, and a cost of \$0.75 kg^{-1} for N, the optimal N rate would be 59 kg ha^{-1} resulting in a maximum economic yield of 3.31 Mg soybean ha^{-1}. An overall seed yield response for these low surface-soil available N environments—all environments had <8 kg NO_3–N ha^{-1} immediately before planting—confirms previous research on soybean response to N fertilizer as affected by available native soil N (Wood et al., 1993; Starling et al., 1998). Environment × cultivar was the only significant interaction ($P = 0.0004$) for seed yield; Kuell yielded significantly more than Prichard at the SMREC 2001 environment, whereas there were no significant yield differences at the other three environments (Fig. 4). Seed yield response to planting date was typical: average seed yield at the first planting date was 3.6 ± 0.07 Mg ha^{-1}, declining by an average of 0.5 Mg ha^{-1} with each advancing date (Table 3).

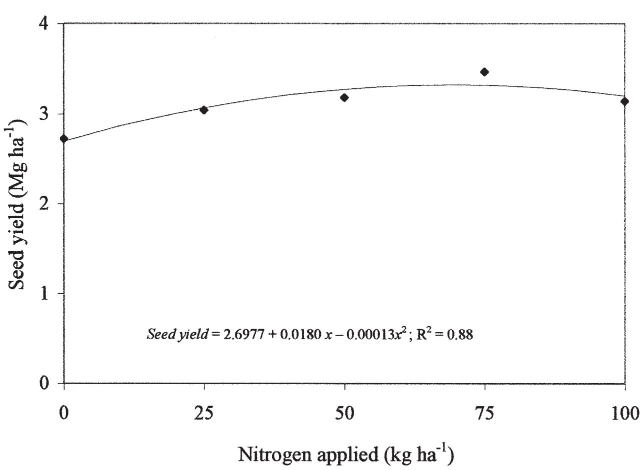

Fig. 3. Seed yield response to application of N averaged over planting dates, environments and cultivars.

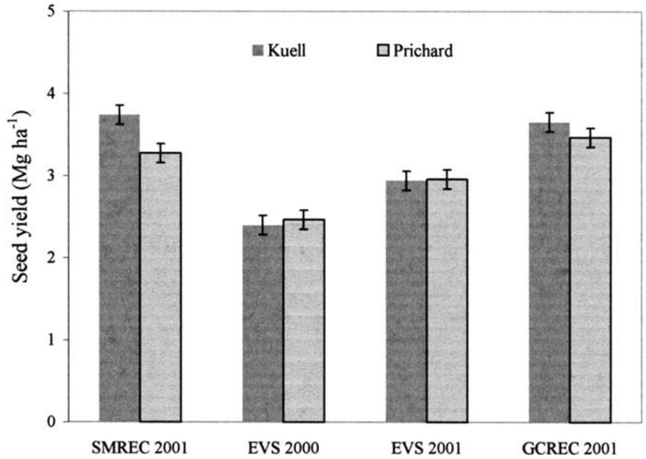

Fig. 4. Effect of cultivar and environment on soybean seed yield averaged over planting dates, N rates, and environments.

Lodging score decreased as planting was delayed. Lodging was increased by applied N, but the increase was dependent on planting date (Table 3). At the first planting date, lodging score was increased from 2.3 at the zero N rate to 3.7 at the 100 kg ha^{-1} N rate. Lodging was increased from 2.2 to 3.2 at the second planting date, but at the third planting date, lodging was not increased by applied N. Thus there was a significant ($P < 0.001$) N rate × planting date interaction for lodging. Lodging scores for the high rates of N at early planting dates could potentially be a production problem. The cultivar × planting date and cultivar × N rate interactions for lodging were not significant.

Seed protein and oil content were unaffected by N application ($P > 0.17$, data not shown). Cultivars were different. Kuell in every case had a lower protein content than Prichard (377 vs. 401 g kg^{-1}, SED = 0.7, P = 0.001) and a correspondingly higher oil content (204 vs. 187 g kg^{-1}, SED = 0.9, P = 0.001). The environment × cultivar × planting date interaction was significant for both protein and oil content ($P < 0.001$), caused primarily by differing response to planting date among the four environments.

There was no consistent seed weight response to N application (data not shown). As is usually the case, environment played the largest role in determining seed weight. Seed weight tended to increase from the northern environment (13.8 g 100^{-1} seed average weight at SMREC) to the more southern environment (16.2 g 100 seed^{-1} at GCREC). Planting date also had an effect on seed weight, with the third planting date always producing the smallest seed. However, differences in seed weight between the first two dates were variable (data not shown), resulting in a significant environment × planting date × N rate interaction ($P < 0.05$). Thus, any increase in seed yield as a result of N application cannot be explained by an increase in this single yield component. It is more likely that applied N resulted in an increase in seed number, but additional research will be required to determine if this is in fact the case. Seed quality score was not affected by any of the treatments (data not shown).

CONCLUSIONS

This study suggests that N applied at planting to late-planted soybean in the Deep South is warranted. The optimal economic rate depends on the cost of N fertilizer and the selling price of soybean. Under the conditions of this study, optimal late-planted soybean R1 dry matter accumulation and seed yield were obtained with 60 to 70 kg N ha^{-1}. Our results indicate that N decreases soybean nodulation in terms of mass and numbers, but greater nodulation at lower N rates did not compensate for N added as fertilizer. Lastly, it appears that N applied to late-planted soybean in the Deep South has no impact on seed mass or quality, or protein and oil content.

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