

Starter Nitrogen and Growth Habit Effects on Late-Planted Soybean

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ABSTRACT

In the Gulf Coast region of the southeastern USA, soybean [*Glycine max* (L.) Merr.] is often planted in a double-cropped system following corn (*Zea mays* L.). In this system, soybean planting date is delayed from the optimal range (mid-May to mid-June) to late July, causing a substantial yield reduction. Potential grain yield response has led to increased interest in indeterminate growth habit and N application for late-planted, double-cropped soybean systems. Our objective was to determine the interactive effects of growth habit (determinate and indeterminate stem termination types) and starter N (0 and 50 kg ha⁻¹) on soybean growth and yield when planted following corn in a double-crop system. Three Maturity Group VIII soybean genotypes [the near-isolines Au86-2397I (*D_tD_t*, indeterminate) and Au86-2397D (*dt₁dt₁*, determinate) and a determinate check cultivar, Cook] were planted in late July in seven Alabama environments during 1995 and 1996. Starter N increased R1 dry matter for both Au86-2397D and Au86-2397I by 0.50 Mg ha⁻¹. Au86-2397I had 1 cm greater average plant height at the R1 developmental stage and 14 cm greater height at R8 than Au86-2397D. Au86-2397I yielded 0.16 Mg ha⁻¹ more than its determinate near-isoline. Application of starter N decreased the number of nodules per root, but increased plant N concentration and dry matter yield. Grain yield was increased on average by 0.15 Mg ha⁻¹ with addition of starter N. In this study, an indeterminate genotype soybean coupled with application of starter N promoted greater soybean growth and yield in a late-planted, double-cropped system.

SOYBEAN is routinely grown in the USA as a second crop after small grains. According to Williamson and Graham (1983) and Wallace et al. (1992), up to one-half of the soybean crop in the southern USA is double-cropped. In the Deep South, it is becoming more common to find soybean grown behind full-season corn. In this cropping system, planting date is delayed to mid or late July from the optimal mid-May through late June (Caviness and Collins, 1985; Flack and Boerma, 1976; Weaver et al., 1991). Because of this delay in planting, yield reduction is commonly associated with double cropping (Egli, 1976; Lewis and Phillips, 1976). Previous studies report that yield reduction in late-planted, double-cropped soybean is associated with a lack of sufficient vegetative growth (Boerma et al., 1982).

Results of comparing the performance of nonisogenic determinate (*dt₁dt₁*) and indeterminate (*D_t*____) soybean genotypes in late-planted environments have been varied. Determinate types have had higher yields in some studies (Wilcox and Frankenberger, 1987; Weaver et al., 1991), while other studies have shown indeterminate types to be superior (Boerma et al., 1982). Indeterminate genotypes may prove to be superior in late-planted environments, due to their greater vegetative

growth compared with determinate soybean (Pyle, 1982).

Application of N fertilizer to soybean has also given varying and contradicting results. Although soybean obtains N through symbiotic fixation, application of N fertilizer has been observed to be beneficial to soybean growth and yield. Application of N as a starter fertilizer has resulted in increased vegetative growth and grain yield (Afza et al., 1987; Al-Ithawi et al., 1980; Eaglesham et al., 1983; Sorensen and Penas, 1978; Touchton and Rickerl, 1986; Wood et al., 1993). Starter N, intended to provide plant-available N to developing seedlings, may be a viable option for late-planted environments with their shortened growing season. However, other studies have shown that soybean either had no response or a negative response to application of N (Beard and Hoover, 1971; Deibert et al., 1979; Ham et al., 1975; Welch et al., 1973). Peterson and Varvel (1989) found reduced grain and dry matter yield with application of N fertilizer. Other studies showed reduction in nodule formation (Chen et al., 1992; Malik et al., 1987; Welch et al., 1973).

Although many studies have evaluated the individual effects of growth habit and N on soybean production, research has not been conducted in the southeastern USA to evaluate the combined effects of growth habit and N rate on late-planted, double-cropped soybean in a single study. Our objective was to determine the interactive effects of starter N (0 and 50 kg ha⁻¹) and growth habit (determinate and indeterminate) on soybean growth and yield when following corn in a late-planted, double-cropped system.

MATERIALS AND METHODS

Experiments were conducted in seven southern Alabama site-year environments in 1995 and 1996 (Table 1). The experiment design was a randomized complete block consisting of six treatments, with four replications in each environment. The treatments were three Maturity Group VIII soybean genotypes [Au86-2397I (*D_tD_t*, indeterminate), Au86-2397D (*dt₁dt₁*, determinate) (Weaver, 1995), and 'Cook'] and two N rates (0 and 50 kg ha⁻¹). Two of the genotypes (Au86-2397D and Au86-2397I) are near-isolines (referred to hereafter simply as *isolines*) that differ only in stem termination type; the other was a determinate control cultivar (Cook). The 50 kg N ha⁻¹ treatment was broadcast-applied by hand and incorporated immediately before soybean planting. The 50 kg N ha⁻¹ rate was chosen because our previous work (Wood et al., 1993) showed that full-season soybean responded to similar N rates. Nitrogen form for the 50 kg N ha⁻¹ treatment was NH₄NO₃. Individual plot size was 3 m wide and 6 m long for all environments.

All sites were managed as double-cropped soybean production systems following full-season corn. Phosphorus and K fertilizers were applied according to Auburn University Soil Testing Laboratory recommendations (Table 1) prior to planting of corn in early March. Pioneer hybrid '3563' corn was

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Table 1. Location names, selected soil characteristics, and planting and harvest dates for seven site-years in Alabama.

Location†	N lat	W long	Soil series	pH	P	K	NO ₃ -N	NH ₄ -N	Planting	Harvest
					kg ha ⁻¹		mg kg ⁻¹			
BEF96	31°08'	87°02'	Benndale fsl (Typic Paleudults)	6.5	79 (H)‡	99 (H)	0.4	0.7	23 July	13 Nov.
EVS96	32°22'	86°00'	Norfolk fsl (Typic Kandiuults)	6.4	77 (M)	185 (VH)	0.8	2.8	23 July	07 Nov.
GCS95	30°33'	87°53'	Malbis fsl (Plinthic Paleudults)	5.9	90 (H)	56 (L)	1.6	8.0	17 July	30 Nov.
GCS96	30°33'	87°53'	Malbis fsl (Plinthic Paleudults)	5.7	44 (M)	125 (M)	0.9	2.8	23 July	22 Nov.
MEF96	31°28'	87°19'	Lucedale fsl (Rhodic Paleudults)	5.7	40 (M)	120 (M)	1.3	3.6	22 July	12 Nov.
WGS95§	31°21'	85°19'	Dothan fsl (Plinthic Kandiuults)	6.2	50 (M)	166 (H)	1.3	8.0	18 July	30 Nov.
WGS96	31°21'	85°19'	Dothan fsl (Plinthic Kandiuults)	6.2	92 (H)	175 (H)	0.4	1.0	18 July	13 Nov.

† BEF96, Brewton Exp. Field in 1996 (Brewton, AL); EVS96, E.V. Smith Field Crops Unit in 1996 (Tallahassee, AL); GCS95 and GCS96, Gulf Coast Substation in 1995 and 1996, respectively (Fairhope, AL); MEF96, Monroeville Exp. Field in 1996 (Monroeville, AL); WGS95 and WGS96, Wiregrass Substation in 1995 and 1996, respectively (Headland, AL).

‡ L, M, H, VH: low, medium, high, or very high soil test ratings (Adams et al., 1994).

§ At WGS95, Stonewall was substituted for Au86-2397I due to seed shortage.

grown for maximum yield and mechanically harvested at maturity. Land preparation after corn harvest consisted of chisel plowing followed by one or two passes with a disk harrow to form an adequate seedbed. Soybean was planted during July (Table 1) using a grain drill with narrow rows (seven rows, 15 cm apart) and seeding rates of 20 seeds m⁻¹ of row.

Herbicides were applied for weed control. Soybean at GCS95 and GCS96 received 2.8 L ha⁻¹ metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] and 0.56 kg ha⁻¹ metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one], broadcast after planting. Soybean at BEF96 received 2.8 L ha⁻¹ of sethoxydim (2-[1-(ethoxymimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one) broadcast over the soybean canopy 2 wk after planting. Soybean at MEF96 received 0.7 kg ha⁻¹ of metribuzin preemergence after planting. At WGS95, no herbicides were applied preplant or preemergence; only as-needed postemergence applications were made. Metolachlor (2.8 L ha⁻¹) was applied to soybean at both WGS96 and EVS96. All sites received additional postemergence applications of herbicides and insecticides for control of specific pests. Overhead irrigation was utilized at EVS96, WGS95, and WGS96. Growing-season precipitation was within normal limits and irrigation was according to standard practice (data available upon request).

Prior to soybean planting, soil samples (0- to 15-cm depth) were taken with a hand probe to determine soil NH₄-N and NO₃-N concentrations. The number of days to maturity (R8) was recorded (Fehr and Caviness, 1977). Root and plant samples were taken at the R1 developmental stage. The developmental stage was recorded for a plot when 50% of the plants reached that stage. Root samples were taken with a 10-cm-diam. sampler to a depth of 20 cm for the Au86-2397D and Au86-2397I isolines only. Roots were then washed using a hydropneumatic root washer to remove soil. Root dry weight and nodule dry weight and number were recorded. Plant dry matter yield at R1 was determined by clipping at the soil surface and collecting 1 m of row length at the soil surface (Herman, 1982). Dry matter yield at R1 was determined gravimetrically following drying of 1-m row samples in a mechanical dryer at 60°C for 48 h. Plants were then ground with a Wiley mill to pass a 1-mm sieve. Plant height was measured (cm) from the soil line to the tip of the mainstem from a single random representative plant for both R1 and R8 developmental stages. Maturity date was reported as the number of days from planting to maturity (when 95% of pods had turned their mature pod color). At maturity, plots were end-trimmed to 5.5 m in length and border rows were removed. Grain harvest was accomplished with a small plot combine. Yields were adjusted to 130 g kg⁻¹ water content. Plant lodging was rated on a scale of 1 to 5, where 1 = erect plants and 5 = prostrate plants.

Soil NH₄-N and NO₃-N concentrations were determined from preplant soil samples using the microplate method (Sims et al., 1995) following extraction with *M* KCl (10:1 KCl:soil). Nitrogen concentration of dried soybean tissue was determined with a LECO CHN-600 analyzer (LECO Corp., St. Joseph, MI). Seed quality evaluation was based on seed coat condition, seed wrinkling, seed shape, and disease presence. Good-quality seed were assigned a value of 1; those of poor seed quality received a value of 5. Seed oil and protein concentration analyses were conducted by the National Center for Agricultural Utilization Research (NCAUR) (Peoria, IL) by near-infrared (NIR) protein and oil analysis (Nelson et al., 1988, p. 188). Seed size was expressed as the weight of 100 randomly selected seeds at 130 g kg⁻¹ moisture.

Data were analyzed by analyses of variance using general linear model procedure provided by the Statistical Analysis System (SAS, 1985). Combined analysis of variance across environments was computed with environments considered random, while genotype and N rate were considered fixed. All main effects and their interactions were determined via *F*-tests.

RESULTS AND DISCUSSION

Early Season Growth

All sites had low concentrations of surface soil NH₄-N and NO₃-N (Table 1). Based on our previous work (Wood et al., 1993), we expected soybean growth and yield responses to starter N at these low-N sites. Plant height at R1 was increased by application of starter N (Table 2). Averaged across genotypes, starter N resulted in R1 plant heights of 37 cm, while plants not receiving N averaged 33 cm. Genotype also affected plant height at R1 (Table 2). Cook (a determinate type) had greater plant height than either Au86-2397D or Au86-2397I at R1 when averaged across N rates (Table 2).

Starter N and genotype interacted to affect soybean dry matter yield at R1 (Table 2). Both the Au86-2397D and Au86-2397I isolines had increased plant dry matter yield with starter N, whereas starter N did not change plant dry matter yield for Cook. These results are contrary to those of Peterson and Varvel (1989), who observed a reduction in dry matter yield with application of N fertilizer. It appears that dry matter response to starter N at the R1 stage of growth is dependent on growth habit and cultivar.

An interaction between genotype and N rate was observed for number of nodules per plant (Table 2), which was determined only for Au86-2397D and Au86-

Table 2. Effects of starter N (0 vs. 50 kg ha⁻¹) and genotype (D, determinate vs. I, indeterminate) on R1 developmental stage traits of late-planted soybean in southern Alabama during 1995 and 1996 (means across seven environments with four replicates).

Genotype†	Plant height at R1			Plant dry matter yield			Nodule count			Nodule dry weight			Plant N concentration		
	Starter N			Starter N			Starter N			Starter N			Starter N		
	0	50	Mean	0	50	Mean	0	50	Mean	0	50	Mean	0	50	Mean
	cm			Mg ha ⁻¹			no. plant ⁻¹			g plant ⁻¹			g kg ⁻¹		
Cook	35	38	37	2.48	2.40	2.44	ND‡	ND	ND	ND	ND	ND	32.4	34.3	33.3
Au86-2397D	32	36	34	2.05	2.57	2.31	31	29	31	0.44	0.33	0.39	33.3	34.3	33.8
Au86-2397I	34	37	35	1.91	2.41	2.16	35	25	30	0.45	0.25	0.35	31.7	33.8	32.7
Mean	33	37		2.14	2.46		33	27		0.44	0.29		32.5	34.1	
ANOVA															
	<i>P</i> > <i>F</i>		LSD (0.05)	<i>P</i> > <i>F</i>		LSD (0.05)	<i>P</i> > <i>F</i>		LSD (0.05)	<i>P</i> > <i>F</i>		LSD (0.05)	<i>P</i> > <i>F</i>		LSD (0.05)
Source of variation															
N rate (N)	0.0001		NA§	0.0008		NA	0.0021		NA	0.0001		NA	0.0002		NA
Genotype (G)	0.0001		1	0.0421		0.21	NA		NA	NA		NA	0.1774		¶
N × G	0.9103		¶	0.0413		0.29	0.0114		5	0.5295		¶	0.8021		¶
Contrast															
D vs. I	0.0001		NA	0.2276		NA	0.3121		NA	0.1621		NA	0.3646		NA
CV, %	9.1			25.1			33.0			56.8			8.5		

† Determinate genotype: Cook and Au86-2397D. Indeterminate: Au86-2397I (Stonewall at one site-year, WGS95).

‡ ND, not determined.

§ NA, not applicable; only two means, no LSD calculated.

¶ No LSD calculated, owing to nonsignificance.

2397I. Starter N decreased number of nodules per plant for Au86-2397I but not Au86-2397D. This reduction in nodulation from starter N (50 kg N ha⁻¹) is contrary to findings of several studies (Deibert et al., 1979; Hardarson et al., 1984; Stone et al., 1985) in which low levels of N resulted in no negative effects on nodulation.

Nodule dry weight per plant was reduced by starter N (Table 2). Averaged across environments and genotype, application of starter N reduced nodule dry weight per plant by 34%. Plots that did not receive starter N application had individual nodule dry weights of 0.013 g nodule⁻¹, compared with 0.011 g nodule⁻¹ for plots that did receive starter N. Although there appeared to be some reduction in individual nodule dry weight, the primary contribution to the reduction in nodule dry weight per plant appeared to be reduction in nodule number. These findings are similar to those of Stone and Buttery (1986).

There was no difference in root weight due to genotype or N rate (data not shown).

Aboveground plant N concentration at R1 was increased by application of starter N (Table 2). Starter N resulted in a 5% increase in plant N concentration. This suggests that starter N increased N supply to the young plants during the early growing season, as was observed by Hardy et al. (1971). Moreover, reduced nodulation owing to starter N (discussed below) had no negative effect on total plant N concentration at the R1 stage of growth. There was no effect of genotype on plant N concentration (Table 2).

Maturity and Harvest

Plant maturity date was not affected by genotype or N rate (data not shown). Plant height at the R8 develop-

Table 3. Effects of starter N (0 vs. 50 kg ha⁻¹) and genotype (determinate vs. indeterminate) on R8 developmental stage traits of late-planted soybean in southern Alabama during 1995 and 1996 (means across seven environments with four replicates).

Genotype†	Plant height at R8			Grain yield			100-Seed weight			Seed protein conc.		
	Starter N			Starter N			Starter N			Starter N		
	0	50	Mean	0	50	Mean	0	50	Mean	0	50	Mean
	cm			Mg ha ⁻¹			g			g kg ⁻¹		
Cook	45	52	48	1.78	2.02	1.90	14.6	14.7	14.6	432	431	431
Au86-2397D	44	46	45	1.74	1.84	1.80	16.4	16.6	16.5	433	440	437
Au86-2397I	67	70	69	1.91	2.02	1.96	16.2	16.4	16.3	438	435	437
Mean	52	56		1.81	1.96		15.7	15.9		435	435	
ANOVA												
	<i>P</i> > <i>F</i>		LSD (0.05)	<i>P</i> > <i>F</i>		LSD (0.05)	<i>P</i> > <i>F</i>		LSD (0.05)	<i>P</i> > <i>F</i>		LSD (0.05)
Source of variation												
N rate (N)	0.0017		NA‡	0.0004		NA	0.3429		NA	0.6969		NA
Genotype (G)	0.0001		2	0.0022		0.09	0.0001		0.3	0.0004		3
N × G	0.1101		§	0.4800		§	0.9011		§	0.0044		4
Contrast												
D vs. I	0.0001		NA	0.0107		NA	0.0001		NA	0.0003		NA
CV, %	9.8			13.9			4.4			1.7		

† Determinate genotype: Cook and Au86-2397D. Indeterminate: Au86-2397I (Stonewall at one site-year, WGS95).

‡ NA, not applicable; only two means, no LSD calculated.

§ No LSD calculated, owing to non-significance.

mental stage was affected by both genotype and N rate (Table 3). Au86-2397I had greater plant height than Au86-2397D at R8 (Table 3). Averaged across N rates, Au86-2397I plant height at R8 was 69 cm, while Au86-2397D had a R8 plant height of 45 cm, only an 11-cm increase in plant height following R1. Application of starter N slightly increased R8 plant height (Table 3). The magnitude of difference in R8 plant height between N treatments was similar to that observed at R1 (Table 2).

Although there were statistical differences in plant lodging scores due to genotype, there was little or no lodging (data not shown). Relatively short plant height (<55 cm) kept lodging scores minimal; only when plant height exceeded 60 cm did we see increased lodging score. Low plant lodging scores support the finding of Boerma et al. (1982), who observed minimal effects of lodging, due to reduced vegetative growth in late-planted double-cropped soybean.

Grain yield was affected by both genotype and N rate (Table 3). Au86-2397I was superior in yield to Au86-2397D across all environments, averaging 1.96 Mg ha⁻¹, compared with 1.80 Mg ha⁻¹ for Au86-2397D (Table 3). Starter N increased grain yield when averaged across all environments. The greatest increase came in the highest-yielding environment (WGS96), where application of starter N boosted grain yield from 2.18 to 2.47 Mg ha⁻¹ (data not shown). Application of starter N increased grain yield by 0.15 Mg ha⁻¹ (9%) when averaged across environments and genotypes. The greatest increases in grain yield were observed in environments with supplemental water sources (EVS96, WGS95, and WGS96) and those that received rainfall within 24 h of N application (GCS96) (data not shown). Our observations of increased grain yield due to starter N are in agreement with those of Afza et al. (1987), Al-Ithawi et al. (1980), Eaglesham et al. (1983), Sorensen and Penas (1978), Touchton and Rickerl (1986), and Wood et al. (1993). Furthermore, these results supported the hypothesis of Wood et al. (1993) that soybean grown on sandy Alabama soils low in N respond positively to application of N fertilizer.

Genotype affected 100-seed weight, with Au86-2397D having a greater average 100-seed weight (Table 3). Although differences between isolines in 100-seed weight were observed, they were small and of little practical significance. Both isolines had greater 100-seed weights than Cook.

There were small differences in seed quality score due to genotype and growth habit (data not shown), but all treatments produced high-quality seed. As was the case with plant lodging score, differences in seed quality score did not have biological significance. Our results suggest that high-quality seed may be produced in the late-planted, double-cropped system, and no distinct advantage in seed quality may be gained through either genotypic selection or N application.

Seed oil concentration was not affected by genotype or N rate (data not shown). Genotype and N rate did interact to affect seed protein concentration (Table 3). Au86-2397I had the highest seed protein concentration

without starter N. Starter N increased seed protein concentration in Au86-2397D from 433 kg ha⁻¹ to 440 kg ha⁻¹. It appears that seed protein concentration response to N varies with genotype.

CONCLUSIONS

Grain yield was increased on average by 0.15 Mg ha⁻¹ with addition of starter N, suggesting that starter N is a viable input for late-planted, double-cropped soybean. Our results also suggest that an indeterminate growth habit may be superior to determinate types for ultra-late planting dates. Although starter N application in these systems appears warranted, we have not pinpointed an N rate expected to promote maximum economic and/or agronomic yield. Future efforts in this line of research should focus on determining appropriate starter N rates in late-planted, double-cropped soybean systems across a variety of environments.

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Changes in Soil Chemical Properties Resulting from Organic and Low-Input Farming Practices

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ABSTRACT

Soil chemical properties during the transition from conventional to organic and low-input farming practices were studied over 8 yr in California's Sacramento Valley to document changes in soil fertility status and nutrient storage. Four farming systems differing in crop rotation and external inputs were established on land previously managed conventionally. Fertility in the organic system depended on animal manure applications and winter cover crops; the two conventional systems received synthetic fertilizer inputs; the low-input system used cover crops and animal manure during the first 3 yr and cover crops and synthetic fertilizer for the remaining 5 yr. At 4 and 8 yr after establishment, most changes in soil chemical properties were consistent with predictions based on nutrient budgets. Inputs of C, P, K, Ca, and Mg were higher in the organic and low-input systems as a result of manure applications and cover crop incorporations. After 4 yr, soils in the organic and low-input systems had higher soil organic C, soluble P, exchangeable K, and pH. Ceasing manure applications in the low-input system in Year 4 resulted in declining levels of organic C, soluble P, and exchangeable K. Crop rotation (the presence or absence of corn) also had a significant effect on organic C levels. Differences in total N appeared to be related in part to inputs, but perhaps also to differing efficiency of the farming systems at storing excess N inputs: the low-input system appeared to be most efficient, and the conventional systems were least efficient. Electrical conductivity (EC), soluble Ca, and soluble Mg levels were tightly linked but not consistently different among treatments. Relatively stable EC

levels in the organic system indicate that animal manures did not increase salinity. Overall, our findings indicate that organic and low-input farming in the Sacramento Valley result in small but important increases in soil organic C and larger pools of stored nutrients, which are critical for long-term fertility maintenance.

THE TRANSITION from conventional to organic and low-input farming is accompanied by changes in an array of soil chemical properties and processes that affect soil fertility. Fundamental differences, both qualitative and quantitative, in the flow and processing of nutrients result from the use of cover crops, manure and compost applications, and reduction or elimination of synthetic fertilizers and pesticides. These changes affect nutrient availability to crops either directly by contributing to nutrient pools or indirectly by influencing the soil chemical and physical environment.

Studies comparing soils of organically and conventionally managed farming systems have documented higher soil organic matter (OM) and total N with the use of organic practices (Lockeretz et al., 1981; Alvarez et al., 1988, 1993; Reganold, 1988; Reganold et al., 1993; Drinkwater et al., 1995). Increases in soil OM following the transition to organic management occur slowly, generally taking several years to detect (Wander et al., 1994; Drinkwater et al., 1995; Werner, 1997), yet can have a dramatic effect on long-term productivity (Tiessen et

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