Nitrogen Fertilizer Effects on Soybean Growth, Yield, and Seed Composition

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While previous research has been contradictory, potential grain yield responses and seed protein increases have led to continuing interest in N fertilizer application to soybean [*Glycine max* (L.) Merr.]. Field experiments were conducted at seven locations from 1990 to 1991 in Alabama to determine soybean response to N fertilization at various growth stages. Treatments included a factorial arrangement of soybean cultivar ('Stonewall' or 'Sharkey') and N rate/timing treatments in a split plot design. Nitrogen rate/timing treatments were: (i) no N, (ii) 30 lb N/acre at planting, (iii) 50 lb N/acre at first bloom (R1), and (iv) 50 lb N/acre at early pod fill (R5). Plant samples were collected at R1 and R5 for dry matter yield and N determination. Grain yields were determined and grain samples were collected at harvest for protein and oil analyses. In general, Stonewall exhibited highest grain yields and seed oil concentrations, while Sharkey had highest protein concentrations. A positive grain yield response to N fertilizer was observed at five of seven locations. Yield responses, however, were inconsistent among those locations with respect to N rate/timing treatments and interaction with soybean cultivar. Grain yield response to N fertilization appeared to be dependent on soil nitrate-N concentration at planting. Nitrogen applied at R5 was the most reliable application time for increasing grain yields, however, yield decreases from N applied at R5 were also observed for both cultivars. Nitrogen fertilization affected seed oil and protein concentrations at only one location. Results of this work suggest that fertilizer-N application to soybean is, at best, a risky proposition.

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Application of N fertilizer to soybean remains a complicated issue owing to conflicting results of previous research. Symbiotic N_2 fixation supplies N for soybean and eliminates the need for large fertilizer-N applications required for nonlegume crops. Nevertheless, only 25 to 60% of N in soybean dry matter originates from symbiotic N_2 fixation, the remainder comes from soil-N (Harper, 1974). Varvel and Peterson (1992) found that soybean plants act as a sink for soil-N and effectively use N regardless of source. Therefore, N fertilization could benefit soybean. Nitrogen fertilizer has had positive effects on soybean growth and yield (Al-Ithawi et al., 1980; Brevedan et al., 1978; Eaglesham et al., 1983; Sorensen and Penas, 1978; Touchton and Rickerl, 1986). However, lack of response—or even negative effects—have also been observed with fertilizer-N applications to soybean (Beard and Hoover, 1971; Diebert et al., 1979; Ham et al., 1975; Welch et al., 1973). For example, in 116 Illinois trials that included a variety of N application methods, Welch et al. (1973) found that only three trials resulted in a positive yield response, and these yield responses were at noneconomic rates of N fertilizer. On the other hand, Sorensen and Penas (1978) observed yield increases with N fertilization at nine of 13 locations in southern Nebraska.

Abbreviations: EVS90, E.V. Smith Research Center, Shorter, AL, 1990 trial; EVS91, E.V. Smith Research Center, Shorter, AL, 1991 trial; MG, soybean maturity group; SMS90, Sand Mountain Substation, Crossville, AL, 1990 trial; SMS91, Sand Mountain Substation, Crossville, AL, 1991 trial; TVS91, Tennessee Valley Substation, Belle Mina, AL, 1991 trial; WGS90, Wiregrass Substation, Headland, AL, 1990 trial; WGS91, Wiregrass Substation, Headland, AL, 1991 trial.

Table 1. Location, selected soil characteristics, and planting and harvest dates for sites used in the study.

Site	Year	Location	Soil series	pH	Organic C	Total N	Ammonium-N	Nitrate-N	P	K	Mg	Ca	Planting date	Harvest date
					— % —		—— lb/acre ——							
EVS90	1990	E.V. Smith Res. Cent.,	Norfolk	5.4	1.0	0.04	6	13	139	287	86	700	28 May	1 Nov.
EVS91	1991	Shorter, AL		5.6	1.0	0.06	5	35	94	253	86	690	4 June	31 Oct.
SMS90	1990	Sand Mt. Substn.,	Wynville	6.1	1.0	0.04	3	2	85	225	142	803	29 May	2 Nov.
SMS91	1991	Crossville, AL		6.1	0.9	0.07	12	9	87	211	109	720	22 May	31 Oct.
WGS90	1990	Wiregrass Substn.,	Dothan	5.9	0.9	0.02	4	0	62	220	132	650	22 May	29 Oct.
WGS91	1991	Headland, AL		5.9	1.4	0.07	50	62	36	82	93	530	30 May	28 Oct.
TVS91	1991	Tennessee Valley Substn., Belle Mina, AL	Decatur	5.5	0.9	0.10	11	24	29	345	135	1660	11 June	31 Oct.

Table 2. Growing season rainfall at seven Alabama locations.

Month	SMS90	EVS90	WGS90	EVS90	SMS91	TVS91	WGS91
	Rainfall (in./mo)						
May	4.1	4.6	3.5	4.8	4.9	9.6	8.8
June	3.5	1.6	2.7	6.4	5.5	1.8	3.1
July	2.0	2.0	3.2	2.7	2.9	2.1	5.8
August	2.0	2.4	1.2	3.8	3.1	2.0	5.6
September	3.9	2.1	0.8	1.9	3.3	3.7	2.7
October	3.4	1.4	2.1	0.4	0.0	2.3	1.2
Total	18.9	14.1	13.4	19.9	19.7	21.4	27.1

In addition to potential yield benefits, changes in soybean marketing strategies have renewed interest in N fertilization to increase seed protein or oil concentration (Helms and Watt, 1991). The USDA-Federal Grain Inspection Service (1989) has recently implemented oil and protein testing as official soybean marketing criteria. These changes, along with improved measurement technology, may induce alterations in the price structure for soybean based on seed composition (Helms and Watt, 1991). Recent research has indicated that late season N applications could increase protein in soybean grain (Gascho, 1991). Much effort has centered around identifying soybean cultivars with desirable seed quality traits along with yield characteristics (Helms and Watt, 1991; Marking, 1990). If premiums are paid in the future for higher protein grain, however, N fertilization may be warranted.

Fertilizer-N application to soybean is based on two precepts of potential soil-N needs during soybean development. Periods in soybean development when soil-N is crucial are: (i) during seedling development prior to nodule formation (Harper, 1974; Hatfield et al., 1974), and (ii) during periods of peak N demand such as pod fill (Diebert et al., 1979).

Starter-N application is directed at providing soybean with readily available soil-N during seedling development, and has been shown to increase soybean grain yields (Touchton and Rickerl, 1986). Fertilizer-N at planting, however, may reduce nodulation and N fixation of soybean (Beard and Hoover, 1971; Weber, 1966). Diebert et al. (1979) reported a 26 to 48% reduction in N fixation when fertilizer-N was applied in excess of 40 lb N/acre at planting, but application of 120 lb N/acre was needed to reduce N fixation if N application was delayed. Similarly, Beard and Hoover (1971) reported a reduction in nodulation with application of more than 50 lb N/acre at planting, but up to 100 lb N/acre could be applied at flowering without affecting nodule number.

The period of high N requirement for soybean is during R3 to R6 (Herman, 1982; Harper, 1971, 1974), and is characterized by peak N fixation (Harper, 1974). Harper (1974) reported both soil-N and fixed-N were needed for maximum soybean yield and that soybean plants at full bloom appear capable of responding to fertilizer-N. Research also has shown that most of the N used by soybean during pod fill is supplied by the soil (Brevedan et al., 1977; Deibert et al., 1979). Nitrogen additions during R3 to R6 have been shown to benefit soybean growth (Brevedan et al., 1978; Gascho, 1991; Oplinger, 1991). Brevedan et al. (1978) reported grain yield increases with N applied at flowering, while others (Gascho, 1979; Oplinger, 1991) observed yield increases with N fertilization during early pod fill.

Although much research concerning response of soybean to N fertilizer has been conducted, few studies have determined early growth, grain yield, and seed composition responses of differing cultivars to N applied at several growth stages. The objective of this study was to examine the effect of fertilizer-N application and timing on early growth, grain yield, and seed protein and oil concentrations of two soybean cultivars with diverse growth habits.

MATERIALS AND METHODS

Experiments were conducted at seven locations during 1990 and 1991 in Alabama. All sites were managed as conventionally tilled, full-season soybean production systems with the goal of optimum, rainfed soybean grain yields. Locations, soil series, selected surface soil (0- to 6-in. depth) characteristics, and planting and harvest dates are given in Table 1; growing season rainfall amounts are presented in Table 2. Soil analyses were performed by the Auburn University Soil Testing Laboratory, according to procedures outlined by Hue and Evans (1986). The soils used in this study were: (i) Norfolk sandy loam (fine, loamy, siliceous thermic Typic Kandiudult) at the E.V. Smith Research Center near Shorter, AL (EVS90 and EVS91); (ii) Wynnville fine sandy loam (fine-loamy, siliceous, thermic Glossic Fragiudult) at the Sand Mountain Substation near Crossville, AL (SMS90 and SMS91); (iii) Dothan fine sandy loam (fine-loamy, siliceous, thermic Plinthic Kandiudult) at the Wiregrass Substation near Headland, AL (WGS90 and WGS91); and (iv) Decatur silt loam (clayey, kaolinitic, thermic Rhodic Paleudult) at the Tennessee Valley Substation near Belle Mina, AL (TVS91). All locations had been planted to soybean in past years, and indigenous rhizobium bacteria populations were considered adequate for soybean nodulation.

Treatments included a factorial arrangement of two

Table 3. Analysis of variance F probabilities for dry matter yield and plant-N content at R1 and R5, grain yield, seed protein and oil concentration, and seed-N content as affected by soybean cultivar and N treatment.

		Location						
Parameter	Source of variation	SMS90	EVS90	WGS90	EVS90	SMS91	TVS91	WGS91
		$P > F$						
R1 dry matter yield	Cultivar, C	0.100	0.883	0.658	0.509	<0.001	0.082	0.827
	N treatment, N	0.638	0.028	0.041	0.372	0.999	0.175	0.282
	N × C	0.545	0.110	0.861	0.197	0.687	0.044	0.186
R1 plant-N content	C	0.007	0.143	0.999	0.601	0.707	0.034	0.574
	N	0.903	0.599	0.050	0.329	0.026	0.097	0.784
	N × C	0.493	0.476	0.688	0.354	0.174	0.450	0.490
R5 dry matter yield	C	0.999	0.334	0.868	0.316	0.402	0.075	0.569
	N	0.888	0.228	0.030	0.545	0.595	0.906	0.291
	N × C	0.731	0.069	0.490	0.992	0.690	0.558	0.103
R5 plant-N content	C	0.991	0.362	0.280	0.520	0.614	0.021	0.443
	N	0.198	0.298	0.183	0.370	0.348	0.669	0.754
	N × C	0.786	0.148	0.558	0.783	0.871	0.612	0.295
Grain yield	C	0.060	0.237	0.138	0.150	0.032	0.310	0.978
	N	0.268	0.072	0.056	0.154	0.054	0.290	0.258
	N × C	0.068	0.062	0.100	0.379	0.133	0.038	0.342
Seed protein concentration	C	0.001	0.102	<0.001	0.002	0.014	0.003	0.029
	N	0.439	0.543	0.287	0.526	0.244	0.005	0.667
	N × C	0.751	0.231	0.233	0.529	0.436	0.046	0.409
Seed oil concentration	C	<0.001	0.006	0.001	0.010	0.005	0.001	0.013
	N	0.424	0.328	0.319	0.499	0.257	0.004	0.812
	N × C	0.967	0.158	0.168	0.397	0.460	0.515	0.314
Seed-N content	C	0.572	0.301	0.190	0.217	0.175	0.502	0.611
	N	0.114	0.060	0.045	0.063	0.018	0.154	0.206
	N × C	0.043	0.064	0.066	0.456	0.136	0.041	0.381

soybean cultivars and four N rate/timing treatments in a split plot design with four replications. Soybean cultivars Stonewall and Sharkey were main plots. Cultivars were selected to provide diversity in maturity date, mature plant height, and seed protein concentration. Sharkey (maturity group [MG] VI) tends to be tall at maturity (≈ 41 in.) with a high seed protein concentration (≈ 43%), while Stonewall (MG VII) has a more compact growth habit (mature height ≈ 35 in.) with a protein concentration averaging 41% (Hartwig and Kenty, 1992). Nitrogen rate/timing treatments were subplots and included: (i) a zero-N control; (ii) 30 lb N/acre at planting (starter); (iii) 50 lb N/acre at first bloom (N at R1); and (iv) 50 lb N/acre at early pod fill (N at R5). The starter N rate (30 lb N/acre) was chosen owing to its common use in the Southeast, when starter-N is applied to soybean (J.T. Touchton, 1990, personal communication). A late-season (R1 and R5) N rate of 50 lb/acre was chosen because previous work in Georgia (Gascho, 1991) indicated the likelihood of it inducing soybean growth, yield, and seed composition responses. Although soybean cultivars were chosen, in part, to provide diversity in maturity date, in actuality the cultivars selected for this study differed very little with respect to time required to obtain specific growth stages. Thus, timing of cultural practices (planting, fertilization, harvests, etc.) were not adjusted between cultivars within locations. All N treatments were applied 2 to 4 in. from soybean rows in a band on the soil surface as ammonium nitrate. Although the locations were managed as rainfed production systems, 1 in. of overhead sprinkler irrigation was applied to all plots after each N application to move N into the soil. Individual plots were 12 ft wide (four 3 ft wide rows), and 25 and 50 ft long in 1990 and 1991, respectively.

Prior to soybean planting, P, K, lime, and other nutrients were uniformly applied to all plots according to recommendations of the Auburn University Soil Testing Laboratory (Cope et al., 1981), and incorporated. Trifluralin was preplant incorporated a at a rate of 0.40 lb a.i./acre for weed control. Additional weed control was achieved via cultivation as needed.

Table 4. Soybean dry matter yield and plant-N content at R1 as affected by N fertilization and cultivar at five locations in Alabama.

		N treatment					
Location	Cultivar	Control	Starter	Mean	Control	Starter	Mean
		lb/acre					
		Dry matter yield			Plant-N content		
SMS90	Stonewall	2003	2235	2119	71.9	77.6	74.7
	Sharkey	2455	2424	2440	95.6	88.6	90.5
	Mean	2229	2330		82.2	83.0	
EVS90	Stonewall	2395	2603	2498	79.8	77.6	78.7
	Sharkey	2069	3043	2556	54.1	68.5	61.3
	Mean	2232	2823		67.0	73.1	
WGS90	Stonewall	848	1092	970	32.8	39.3	36.1
	Sharkey	877	1157	1017	31.4	40.2	35.8
	Mean	863	1125		32.1	40.0	
SMS91	Stonewall	1590	2033	1811	65.1	71.5	68.3
	Sharkey	1745	2188	1967	64.0	84.5	74.3
	Mean	1667	2110		64.6	78.0	
	Stonewall	1576	2003	1789	55.3	72.4	63.9
TVS91†	Sharkey	2249	2144	2197	80.5	87.6	84.0
	Mean	1912	2074		67.9	80.0	

† A cultivar × N treatment interaction occurred at TVS91 for dry matter yield ($LSD_{0.1}$ = 329).

Soybean plants from 3.3 ft of row were clipped at ground level at the R1 and R5 stages of growth (Herman, 1982) for dry matter yield and N determination. Soybean plants were collected from the zero-N control and starter treatments at R1, while at R5, plants were collected from the zero-N control, starter, and N at R1 treatments. After drying at 140°F and dry matter yield determination, soybean plants collected at R1 and R5 were ground to pass a 0.02-in. sieve. Nitrogen was determined on the ground samples with a LECO CHN-600 analyzer (LECO

Table 5. Soybean dry matter yield at R5 as affected by N fertilization and cultivar at three locations in Alabama.

Location	Cultivar	N treatment				LSD (0.1)†	
		Control	Starter	N at R1	Mean	N	N × C
		Dry matter yield, lb/acre					
SMS90	Stonewall	4407	5422	4611	4813	590	NS
	Sharkey	4632	5130	4678	4813		
	Mean	4520	5276	4644			
EVS90	Stonewall	4822	5477	6260	5406	NS	1752
	Sharkey	6025	7140	5273	6146		
	Mean	5254	6308	5766			
WGS90	Stonewall	4269	5878	4255	4801	854	NS
	Sharkey	4875	5326	4087	4763		
	Mean	4572	5602	4171			

† N = N treatment; C = cultivar; cultivar has only two means, no LSD value given; NS = not significant at $\alpha = 0.1$.

Corp., St. Joseph, MI). Grain yields were determined by harvesting the two center rows of each plot with a plot combine. Grain samples were collected from each plot at harvest for moisture, protein, and oil determinations. Grain yields are reported at 13.0% moisture. Seed protein and oil analyses were performed by the National Center for Agricultural Utilization Research using the procedures of Nelson et al. (1988). Nitrogen content in plants at R1 and R5, and seed protein and oil concentrations are reported on a 0% moisture basis.

Data were analyzed using ANOVA and GLM procedures of SAS (SAS Institute, 1988). Since significant location-year × independent variable interactions existed for most dependent variables in this study, each location was analyzed separately. Unless noted otherwise, all statistical tests were performed at the $\alpha = 0.10$ level of significance.

RESULTS AND DISCUSSION

Early Season Growth

Vigorous early season growth is important for development of soybean plant architecture that supports grain production. At the R1 and R5 growth stages, fertilizer-N application altered either dry matter production or plant-N content at five (SMS90, EVS90, WGS90, SMS91, and TVS91) of seven locations (Table 3). At two locations, EVS91 and WGS91, neither soybean cultivar nor N treatment had a significant effect on dry matter production or plant-N content at R1 or R5 (Table 3).

At R1, starter-N increased soybean dry matter yield at three locations (EVS90, WGS90, and TVS91) (Tables 3 and 4). Dry matter yields at the R1 growth stage were 26 and 30% greater for the starter-N treatment than for the zero-N control at EVS90 and WGS90, respectively (Table 4). At TVS91, starter-N increased R1 dry matter yield of Stonewall only (27% increase over the control), as evidenced by the significant cultivar by N treatment interaction (Table 3). Sharkey had greater R1 dry matter yields than Stonewall at SMS90 and SMS91, and for the zero-N control at TVS91 (Tables 3 and 4).

Plant-N content at R1 was affected by N treatment at WGS90, SMS91, and TVS91 (Table 3). At these locations, starter-N resulted in greater R1 plant-N content than the zero-N control (Table 4). Sharkey had higher

Table 6. Soybean grain yield as affected by N fertilization and cultivar at five locations in Alabama.

Location	Cultivar	N treatment					LSD (0.1)†	
		Control	Starter	N at R1	N at R5	Mean	N	N×C
		Grain yield, bu/acre						
SMS90	Stonewall	55.2	54.4	52.5	52.2	53.5	NS	2.4
	Sharkey	47.9	47.8	46.4	51.4	48.3		
	Mean	51.6	49.4	51.9				
EVS90	Stonewall	27.5	39.5	42.1	29.6	34.6	4.9	7.0
	Sharkey	24.8	32.9	27.2	36.6	30.3		
	Mean	26.2	36.1	34.6	33.0			
WGS90	Stonewall	24.5	27.8	23.2	27.9	25.9	1.8	2.5
	Sharkey	19.6	22.2	24.2	23.9	22.4		
	Mean	22.0	25.0	23.6	26.0			
SMS91	Stonewall	43.0	44.6	43.3	43.3	42.8	1.5	NS
	Sharkey	37.0	37.8	36.4	41.6	38.2		
	Mean	40.0	39.7	39.8	42.5			
TVS91	Stonewall	44.0	44.9	48.3	54.9	48.0	NS	4.9
	Sharkey	48.6	43.1	47.6	43.0	45.5		
	Mean	46.4	44.0	47.9	48.9			

† N = N treatment; C = cultivar; cultivar has only two means, no LSD value given; NS = not significant at $\alpha = 0.1$.

plant-N contents than Stonewall at SMS90 and TVS91 (Tables 3 and 4).

Nitrogen fertilization had an effect on R5 dry matter yield and plant-N content at fewer locations than was observed at R1. Significant effects of fertilizer-N on R5 dry matter yield were exhibited at three locations (SMS90, EVS90, and WGS90) (Table 3). At SMS90 and WGS90, starter-N increased R5 dry matter yield over the zero-N control and the N at R1 treatment (Table 5). At EVS90, owing to the significant cultivar × N treatment interaction (Table 3), N at R1 resulted in greater soybean dry matter yield at R5 than the zero-N control for Stonewall, while starter-N increased dry matter yield over the N at R1 treatment for Sharkey. Nitrogen applicaton had no effect on R5 plant-N content at any location (Table 3), even though seed-N content at harvest was modified by N treatments at four locations (Table 3).

Although N fertilization increased early-season soybean growth at five of seven locations in Alabama, the data were not conclusive. Starter-N appeared to offer the greatest benefit to early growth and plant-N content where soybean growth responses were observed. Early-season growth responses were inconsistent, however, between cultivars and among locations. Therefore, no general inferences concerning the effects of N fertilization on early season soybean growth can be drawn from these data.

Grain Yield

Soybean grain yield was affected by the N rate/timing treatments at five locations (SMS90, EVS90, WGS90, SMS91, TVS91) (Table 3). As was observed with early growth, no significant effect of either soybean cultivar or N treatment was present at EVS91 or WGS91, with an average yield of 34.9 and 31.4 bu/acre, respectively. At EVS91 and WGS91, surface soil nitrate-N content at planting was much higher than the five locations where yield was affected by N treatment (Table 1). Several studies have demonstrated that soybean yield response

Table 7. Soybean seed-N as affected by N fertilization and cultivar at five locations in Alabama.

Location	Cultivar	N treatment					LSD (0.1)†	
		Control	Starter	N at R1	N at R5	Mean	N	N × C
		N content, lb/acre						
SMS90	Stonewall	210	213	204	204	210	NS	4
	Sharkey	204	204	197	220	206		
	Mean	212	208	200	212			
EVS90	Stonewall	116	165	177	128	146	26	44
	Sharkey	108	141	118	156	131		
	Mean	112	153	148	142			
WGS90	Stonewall	106	121	99	122	112	10	28
	Sharkey	88	98	107	106	100		
	Mean	97	110	104	114			
SMS91	Stonewall	171	168	171	175	171	8	NS
	Sharkey	156	158	152	176	160		
	Mean	164	163	162	175			
TVS91	Stonewall	151	153	177	205	171	NS	34
	Sharkey	189	168	183	170	177		
	Mean	170	160	178	187			

† N = N treatment; C = cultivar; cultivar has only two means, no LSD value given; NS = not significant at $\alpha = 0.1$.

to fertilizer-N is dependent on soil nitrate-N content (Al-Ithawi et al., 1980; Lamb et al., 1990; Stone et al., 1985). Stone et al. (1985) reported that as soil nitrate-N at planting increased, soybean response to fertilizer-N declined, while Al-Ithawi et al. (1980) concluded that soybean response to fertilizer-N depends on both soil nitrate-N and soil moisture contents. Apparently, soybean response to fertilizer-N in Alabama is also dependent on soil nitrate-N content at planting.

At the five other locations (SMS90, EVS90, WGS90, SMS91, TVS91), soybean grain yield was affected by both N treatment and cultivar, with an interaction occurring between these factors at four of the five locations (Table 3). In general, Stonewall produced higher grain yields than Sharkey (Table 6). When averaged across N treatments and locations, Stonewall produced approximately 4 bu/acre more than Sharkey. Nitrogen fertilization effects on grain yield were inconsistent among locations. Crop yield response to both N rate/timing treatment and soybean cultivar differed with location (Table 6). While increased yield due to N fertilization was observed at each of the five locations, significant yield decreases due to fertilizer-N were oberved at two locations (Table 6). Yield reductions due to N fertilization were observed with both cultivars but at different locations. With N fertilization, Stonewall had yield reductions at SMS90, while Sharkey had yield reductions at TVS91 (Table 6). In both cases, a yield increase for the other cultivar was oberved with the same N rate/timing treatment at the same location. The reason for these inconsistences in grain yield response to N fertilization between cultivars and among the five responsive locations is unclear.

The most consistent grain yield increases from N fertilization were observed at EVS90 and WGS90 (Table 6). Yields for these locations, however, were lower than for the five other locations, with average control yields of 26.2 and 22.0 bu/acre at EVS90 and WGS90, respectively. Nitrogen response at these locations is consistent with results of a study conducted in southeastern Nebraska by Sorensen and Penas (1978). They reported that declining soybean yields (among locations) were associated with greater potential yield response to fertilizer-N. They speculated that environmental limitations on soybean growth may restrict N fixation, resulting in a positive response to fertilizer-N. Environmental stress may be a plausible explanation for the N response at EVS90 and WGS90. Drought occurred at these locations in 1990 (Table 2). In 1991, precipitation amounts were greater at these locations than in 1990 (Table 2), and mean control yields increased, relative to 1990 yields, to 36.0 bu/acre at EVS91 and 31.7 bu/acre at WGS91. Greater rainfall in 1991, along with high levels of soil nitrate-N (Table 1), apparently contributed to the absence of a N response at EVS91 and WGS91 (Tables 3 and 6).

Table 8. Soybean yield break-even point of fertilizer-N application with varying cost of N and return on soybean.†

	Cost of N	Return on soybean, $/bu				
		$5.50	$5.70	$5.90	$6.10	$6.30
		Break-even point, bu/acre				
Starter‡	0.26	1.4	1.4	1.3	1.3	1.2
	0.28	1.5	1.5	1.4	1.4	1.3
	0.30	1.6	1.6	1.5	1.5	1.4
	0.32	1.7	1.6	1.6	1.6	1.5
N at R1 or R5‡	0.26	2.4	2.3	2.2	2.1	2.0
	0.28	2.5	2.5	2.4	2.3	2.2
	0.30	2.7	2.6	2.5	2.5	2.5
	0.32	2.9	2.8	2.7	2.6	2.5

† Break-even point does not include spreading costs.
‡ Starter = application of 30 lb N/acre at planting, N at R1 = application of 50 lb N/acre at first bloom, and N at R5 = application of 50 lb N/acre at early pod fill.

Nitrogen fertilization impacts on soybean yield were much more variable at the three other locations (SMS90, SMS91, and TVS91) with a positive response to N fertilizer (Table 6). At SMS90 and TVS91, N treatment interacted with cultivar (Table 3). At these locations (SMS90 and TVS91), N at R5 resulted in highest grain yields. At SMS90, N at R5 increased the yield of Sharkey by 3.5 bu/acre. Nitrogen at R5 increased yield by 10.9 bu/acre for Stonewall at TVS91. At SMS91, N at R5 resulted in an average soybean yield increase of 2.5 bu/acre (Table 6). Starter-N or N at R1 did not increase yield at any of these three locations (Table 6).

Seed Composition

Seed protein and oil concentrations varied significantly between cultivars at all locations (Table 3). At all locations, Sharkey had significantly higher seed protein concentration, with an average (across locations) of 44.5% compared with 42.2% for Stonewall. Conversely, at all locations, Stonewall produced significantly higher seed oil concentrations, with an average (across locations) of 20.1% compared with 17.4% for Sharkey.

Except at TVS91, fertilizer-N did not affect oil and protein concentrations of soybean seed (Table 3). While differences in seed-N content (lb N/acre) due to N application were observed at most locations (Tables 3 and 7), these differences were not manifested as differences in soybean protein concentration, but rather as changes in seed yield. At TVS91, N at R5 reduced seed oil concentration. A significant N treatment × cultivar interaction at TVS91 indicated that N at R5 resulted in a greater percentage increase in seed protein concentration (relative to the control) for Stonewall (9.5%) than Sharkey (1.7%). Nitrogen at R1 resulted in increased seed protein concentration at TVS91 for Stonewall only, with a 5.4% increase over the control. Starter-N did not affect protein or oil concentrations at any location.

Our results indicate that N fertilization would not be an effective means of altering protein and oil concentrations of soybean in Alabama. Selection of cultivars with the desired oil and protein concentrations would be a more reliable method of producing soybean with characteristics for a discount/premium price advantage based on seed composition.

Except for WGS91, seed-N content was affected either by N treatment alone or by N treatment and cultivar interactively (Table 3). Nitrogen content of soybean seeds was reflective of soybean yields, with differences due to cultivar and both positive and negative response to fertilizer-N (Table 7). Although seed-N content was highly variable, with the control having both the highest and lowest level of seed-N, N at R5 often resulted in the highest seed-N content. Consequently, N at R5 may be the most reliable N application method to increase N use in soybean plants.

Economic Benefit

The economics of N application to soybean are dependent on three factors: fertilizer price, fertilizer amount, and soybean price. Since soybean can be grown satisfactorily without N fertilization, fertilizer expenditures must be balanced by additional return on soybean grain to warrant N applications. The point at which N fertilization could be considered profitable (break-even point) depends on fertilizer costs, and return on grain. Table 8 illustrates changes in the break-even point as soybean and N fertilizer prices change, and is based on 30 lb N/acre for starter-N and 50 lb N/acre for late season N applications.

A comparison of grain yield data (Table 6) to the break-even point (Table 8) indicates that positive responses to fertilizer-N observed in this study would result in an economic benefit, even at the highest N cost and the lowest return on soybean grain. While a positive response to N occurred at five of the seven locations, however, the response was highly variable and impossible to predict. Yield response was dependent on both application time and cultivar, with varying response to these factors at different locations. In addition, the data suggest that yield response of soybean to fertilizer-N in Alabama is dependent on soil nitrate-N content at planting.

Our results indicate that application of N fertilizer to soybean in Alabama is a dubious practice. This is demonstrated by using the average price for N at $0.28/lb (Goodman et al., 1992) and soybean at $5.90/lb (Alabama Farm Facts, 1992) in Alabama for 1991. The potential benefit of N fertilizer application to soybean was as much as $86.14/acre (R1 application and Stonewall cultivar at EVS90), but this must be balanced against potential losses. For example, N at R5 was the most reliable time of application for both cultivars, with a cost of $14/acre that would not be recovered when yield response is lacking or negative. At TVS91, the Stonewall cultivar with N at R5 would be expected to return a net profit of $64.31/acre above N costs. In contrast, the same application would result in a net loss of $32.40/acre if applied to the Sharkey cultivar. Similar results were observed at the SMS90 location, but with Sharkey resulting in a net profit and Stonewall resulting in a net loss.

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