Nitrogen and Boron Applications During Reproductive Stages for Soybean Yield Enhancement

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(Abstract)

The yield response of soybean [*Glycine max* (L.) Merr.] to reproductive stage applications of either nitrogen (N) or boron (B) has been inconsistent. This study evaluated soybean seed yield response to foliar applications of B and soil applications of N at two stages of plant development, at two row spacings, at four irrigation levels, and on three cultivars over three years. Planting dates were either mid-May or mid-June, except the year two of the irrigated soil moisture experiment which had a second planting date of early July. In an experiment to evaluate B rate and timing, B was applied at four rates from 0 to 0.56 kg ha^{-1} at the R3 or R5 development stage. In an experiment to evaluate N rate and timing, N was applied at seven rates from 0 to 168 kg ha^{-1} at either the R3 or R5 development stage. A third experiment to evaluate row spacing and cultivar effects on N and B had four treatments: 0 N and 0 B; 56 kg ha $^{-1}$ N, and 0 B; 0 N and 0.28 kg ha^{-1} B; and finally 56 kg ha^{-1} N and 0.28 kg ha^{-1} B. Treatments were applied to three soybean cultivars planted in either 23 or 46 cm row spacings. The above experiments were irrigated to evaluate treatments at high yield levels. To further evaluate the effect of soil moisture, the same four N and B combinations were applied to soybeans irrigated via a sub-surface micro-drip irrigation system delivering four irrigation regimes: 0%, 33%, 66%, or 100% of plant required water. Gradients were established in year one of this experiment, but late season rains eliminated gradients, and high rainfall in the second year disallowed gradient establishment. Applications of N or B had no effect on seed yields in any experiment, or at any moisture level. In the row spacing and cultivar experiment, there were significant effects of varieties, and a significant interaction between row spacing and variety in two of the three years.

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Chapter 1.—Introduction and Justification

Soybean (*Glycine max* (L.) Merr.) is an important cash crop throughout the Mid-Atlantic region of the USA (DE, MD, NC, PA, and VA). Planted area for the five-state region have approached 1.25 million ha during both 1998 and 1999 (N.A.S.S., 2000). Soybean production generated \$574 million and \$474 million for the area in 1997 and 1998, respectively, and soybean ranks in the top five crops for hectares planted and total cash receipts generated in each state within the Mid-Atlantic growing region. These figures clearly demonstrate the importance of soybean, as well as the potential economic benefits possibly realized from productivity increases.

Although the importance of soybean in the Mid-Atlantic states is clear, the average yield of this region consistently lags behind that of the Midwestern states. Average Mid-Atlantic yields were 670 kg ha^{-1} less than that of 10 Midwestern states in both 1997 and 1998 (N.A.S.S., 2000). Such a yield discrepancy puts Mid-Atlantic states at a competitive disadvantage with the major soybean producing regions of the U.S. Furthermore, lower market prices, reflecting increasing world competition, have also affected the profitability of the Mid-Atlantic soybean crop. Thus, it is imperative to find methods to boost soybean yields without reducing yields of other key crops in the rotation, in order to keep soybean production viable in the Mid-Atlantic region.

This project is a companion study to the Mid-Atlantic Regional Interdisciplinary Cropping Systems Project. This parent project is a multi-state research endeavor with objectives to increase yield, improve profitability, and maintain the natural resource base. In Virginia a 24.3 ha site has been established to evaluate three cropping systems, all utilizing best management practices, commercial farm equipment, and site specific agriculture techniques under rainfed conditions. The rotations being tested are 1) no-till full season corn, conventional-till wheat, no-till double crop soybeans (3 crops in 2 years); 2) no-till corn, no-till full season soybeans, no-till wheat, no-till double crop soybeans (4 crops in 3 years); and 3) no-till wheat, no-till double crop soybeans, no-till barley, no-till double crop corn (4 crops in 2 years). As each component of a system is improved, its interaction with the entire system is evaluated allowing the assessment of the viability of the entire system. Since soybean is an essential component in each cropping system, an increase in soybean productivity without decreasing system productivity overall translates into a more economically viable cropping system for the Mid-Atlantic region.

Intensification of systems pushing yields upward demands precise management of fields for optimum levels of all nutrients, both macro and micro. In these high yielding situations, levels of nutrients thought to be adequate may, in fact, be limiting plant growth. Supplemental applications of N and B have occasionally been shown to increase soybean yields (Wesley, et al., 1998; Purcell and King, 1996; Syverud, 1980; Garcia and Hanway, 1976; Reinbott and Blevins, 1995; Schon and Blevins, 1990; Touchton and Boswell, 1975; Gascho and McPherson, 1997). This research project examines the yield effects of reproductive stage applications of N and B on soybean in the Mid-Atlantic region.

Soybean demand for N, one of the highest of any crop, can exceed 90 g N per kg of soybean seed (Flannery, 1986). Supply for this high N demand comes predominately via symbiotically fixed N when soybeans are inoculated with the correct *Bradyrhizobia* strains. Due to the physiology of the soybean plant, the majority of N demand occurs when seed development begins, at the R5 development stage (Fehr and Caviness, 1977; Harper, 1987; Herman, 1997; Holshouser, 1998). At this time, the seeds become the nutrient sinks, and remobilization of N incorporated in other sites within the plant occurs, allowing translocation into the developing seeds. While much of the N demand can be supplied via symbiotically fixed N and remobilized N, it is possible that under high yielding conditions N could be limiting optimum seed production. However, the N application must occur during the reproductive stages of plant growth, since early N applications decrease *Bradyrhizobia* activity (Yoneyama, et al., 1985; Bhangoo and Albritton, 1976; Ham, et al., 1975; Yoshida, 1979).

As macronutrient needs are met, it becomes possible that micronutrient requirements of the soybean plant could be limiting optimum production, and although boron is termed a micronutrient, its role within the plant is widespread. The role of boron within the plant includes cell wall synthesis, sugar transport, cell division, differentiation, membrane functioning, root elongation, and regulation of plant hormone levels (Marschner, 1995; Romheld and Marschner, 1991). Moreover, it is recognized as one of the most commonly deficient micronutrients in agriculture, with reports of deficiencies in 132 crops and in 80 countries (Shorrocks, 1997). Boron leaching is most prevalent in humid areas with coarse textured soils leading to deficiencies (Mortvedt and Woodruff, 1993; Marschner, 1995; Welch, et al., 1991), such as are found in the soybean production areas of the Mid-Atlantic region. Additionally, as average yields rise, levels of B accepted to be adequate may actually be insufficient.

A final aspect of this project examined N and B combinations. Data for N and B applications to soybean are scarce for any location, and not available for the Mid-Atlantic region, justifying further research. Research from Georgia examining the effects of N and B on soybean reports that fertigation using N and B applied together have increased total dry matter yields by 5980 kg ha^{-1} over irrigated control yields of 9150 kg ha^{-1} (Gascho, 1992). In this same study, spray applications of N and B made at R5 increased seed yield by 470 kg ha^{-1} over the control yield of 2890 kg ha^{-1}.

In the sandy soils of the Mid-Atlantic growing region, B deficiency may be occurring under high yielding conditions. Also, even if B is not deficient, applications of B have been reported to boost yields (Reinbott and Blevins, 1995; Schon and Blevins, 1990; Touchton and Boswell, 1975). Similarly, N applications made during reproductive development stages may increase soybean seed yield (Wesley, et al., 1998; Purcell and King, 1996; Syverud, 1980; Garcia and Hanway, 1976). If B applications can increase the number of pods, pod retention, sugar transport into developing seed, the supplemental N applied will be available for seed fill, thus increasing yield. The objectives of this experiment were to:

1. Determine the effect of B rate and application timing (R3 vs. R5) on soybean seed yield
2. Determine the effect of N rate and application timing (R3 vs. R5) on soybean seed yield
3. Determine the effect of cultivar and row spacing on the yield response of soybean seed yield to N and B applications at the R3 stage
4. Determine the effect of soil moisture, representing yield potential, on the yield response of soybean to N and B applications.

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Chapter 2—Soybean Yield Response to Reproductive Stage Boron Applications

ABSTRACT:

Soybean [*Glycine Max* (L.) Merr] yield response to boron (B) applications has been inconsistent. This research examined the effect of reproductive stage B applications on soybean yields over a three year period in the coastal plain region of Virginia. Treatments were a factorial arrangement of four B rates (0, 0.14, 0.28, or 0.56 kg ha^{-1}), using disodium octaborate tetrahydrate dissolved in 94.5 L ha^{-1} of water, and applied as a foliar spray to either R3 or R5 soybean. Plots were irrigated to prevent drought stress. Applications of B did not increase yield at any rate or any stage, regardless of year or yield potential. The lack of response to supplemental B suggests that native levels of B in soils are adequate for high yields in the coastal plain production region of Virginia.

Soybean Yield Response to Reproductive Stage Boron Applications

Boron is a micronutrient because of concentration levels in plant tissue, not because of importance in plant growth. Boron's widespread role within the plant includes cell wall synthesis, sugar transport, cell division, differentiation, membrane functioning, root elongation, and regulation of plant hormone levels (Marschner, 1995; Romheld and Marschner, 1991; Pilbeam and Kirkby, 1983). Boron is one of the most commonly deficient micronutrients in agriculture, with reports of deficiencies in 132 crops and in 80 countries (Shorrocks, 1997). These deficiencies typically result from boron leaching occurring in humid areas with coarse textured soils (Mortvedt and Woodruff, 1993; Marschner, 1995; Welch, et al., 1991).

Gascho and McPherson (1997) reported yield benefits from foliar B applications over the control yield on an irrigated Bonifay sand in Georgia. The application of 0.28 kg B ha^{-1} at soybean development stage as defined by Fehr and Caviness (1977) generated yields averaging 353 kg ha^{-1} higher than the control yield of 3247 kg ha^{-1}, averaged over five cultivars at the same site. In this study, three out of five cultivars showed significant response to B applications at any rate, leading the authors to believe that yield response to B may depend on cultivar. Other researchers from Georgia report that B mixed with diflubenzuron [1-(4-chlorophenyl) 3-(2,6-difluorobenzoyl)urea] insecticide applied to R2 or R3 increased yield by an average of 23% at four sites (Hudson and Clarke, 1997). The yield level for the untreated check averaged 2580 kg ha^{-1} while the B+diflubenzuron treated plots applied at R2 to R3 yielded 3185 kg ha^{-1}. Similarly, on a loamy sand, two split B applications at ½ the treatment rate, the first applied at R1 and the second seven days later, increased yields by 4% for rates up to 1.12 kg ha^{-1} (Touchton and Boswell, 1975).

Direct infusions of soybean plants growing on a Mexico silt loam soil with supplemental B using H_3BO_3 as the source have caused an 84.8% increase in the total number of branch pods per plant as well as an increase of 17.6 % in total seed weight per plant (Schon and Blevins, 1987). Seed yield in this experiment corresponded to 4170 kg ha^{-1} for B injected plants and 3540 kg ha^{-1} for the control plants. During this experiment, the yield increase was due to an increase in the number of pods per plant. On the same Mexico silt loam soil in Missouri utilizing the same soybean cultivar, two foliar applications of B at R1and R2 increased the number of pods per branch (Schon and Blevins, 1990). In another experiment, six split applications from R1 through R8 increased both the number of pods per branch and the number of branches per plant (Schon and Blevins, 1990). Similarly, two foliar applications at R4 and R5 caused a yield increase of 356 kg ha^{-1} on a Mexico silt loam in Missouri (Reinbott and Blevins, 1995).

Soil applied B rates of 2.8 kg ha^{-1} in a silty clay loam produced soybean yield increases of 11% and 13%, respectively, in the first two years with no effect in the third year after application respectively (Reinbott and Blevins, 1995). These increases corresponded to yields of 1931 kg ha^{-1} and 1934 kg ha^{-1} compared to the control yield of 1736 kg ha^{-1} and 1687 kg ha^{-1} for years one and two, respectively. In these studies, soil applied B increased pods per branch by 17% and number of pods per plant by 39%. A late planting date in the third year possibly contributed to the lack of response. Broadcast applications of B at 0.28 to 1.12 kg ha^{-1} at three sites in Georgia generated variable results, but soybean yield was increased by 4% on a coastal plain soil (loamy sand) with low soil test B levels (0.14 ppm hot-water-soluble B) (Touchton and Boswell, 1975). Research in Arkansas on a silt loam soil reported yield increases up to 538 kg ha^{-1} over the control yield of 2861 kg ha^{-1} to soil applied B during early flowering at a rate of 3 kg ha^{-1} (Al-Molla, 1985). At another site on a silt loam soil, Al-Molla (1985) reported a yield increase of 569 kg ha^{-1} over the control yield of 2257 kg ha^{-1} with a B application of 4 kg ha^{-1} made to the soil at early flowering.

In contrast to these positive yield responses, soil applied B on a silt loam in Missouri at rates of 0.0, 0.28, 0.56, and 1.12 kg ha^{-1} generated no significant differences in yield or yield components (Schon and Blevins, 1990). No yield effect was also observed on a silt loam in Missouri with split foliar applications of B at rates of either 0.56 or 1.12 kg ha^{-1} applied at R2 and R3 (Reinbott and Blevins, 1995). Similarly, B applied at rates up to 3.3 kg ha^{-1} on a clay loam and a fine sandy loam in Virginia had no effect on soybean yield over six years (Martens, et al., 1974). No significant yield effects were observed with soil applied B at rates up to 1.12 kg ha^{-1} in a sandy loam in Georgia, and yield reductions of 10% were observed at one site when a B rate of 2.24 kg ha^{-1} was utilized (Touchton and Boswell, 1975).

These variable results demonstrate the need for further research on B applications to soybeans. Application timing, rate, and conditions necessary for a yield response have not yet been fully determined. Foliar application of B deposits B where needed, alleviating leaching concerns in coarse textured soils, allows application rates of approximately 50% less than soil applied rates, and enables the producer to apply B at the critical plant growth stages (Martens and Westermann, 1991; Mortvedt and Woodruff, 1993). Additionally, levels of B accepted to be adequate may actually be insufficient as higher yields are obtained. The objective of this experiment was to determine the effects on soybean yield of B applications at four rates and two growth stages on sandy Coastal Plain soils of the Mid-Atlantic soybean-growing region under high-yielding irrigated conditions.

MATERIALS AND METHODS

Deltapine soybean cultivar DP 3478 was planted in mid-May at a population of 263,000 and 272,000 plants ha^{-1} in 1997 and 1998, respectively, on a Nansemond fine sandy loam (coarse-loamy, siliceous, thermic, Aquic Hapludult) in Suffolk, Virginia. In 1999, soybeans were planted in mid-June at a population of 432,250 plants ha^{-1} in a State fine sandy loam (fine loamy, mixed, semiactive, thermic Typic Hapludult) near Mt. Holly, Virginia, following barley harvest. The plant population increase in the Mt. Holly location follows Virginia Cooperative Extension recommendations for late planting after small grain harvest (Holshouser, 1998). Plot size was four 46-cm wide rows by 7.3 m long. To prevent moisture stress, experiments were irrigated using sub-surface micro-drip irrigation in 1997 and 1998 and an overhead center pivot system in 1999. In 1997, 15-cm deep soil samples were taken at planting and tested for available nutrients (Table 1). In 1998 and 1999, soil samples were taken at emergence from depths of 0-15, 15-31, 31-61, 61-91 cm and tested for available nutrients (Table 1). Plant tissue samples were taken randomly from the uppermost fully expanded leaves at R1, before treatment application and analyzed for nutrient content (Table 2). In 1997, both P_2O_5 and K_2O were applied at 45 kg ha^{-1} prior to planting. No fertilizer was applied in 1998, as nutrient levels were adequate for high yields. In 1999, 67.2 kg ha^{-1} P_2O_5 and 112 kg ha^{-1} K_2O were applied before barley planting.

In 1997-1998, metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] + metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one] was applied preemergence at 1.4 + 0.28 kg ai ha^{-1} , respectively. In 1999, metolachlor + sulfentraxone {N-[[2,4-dicloro-5-(4-difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide} + chlorimuron-ethyl {ethyl 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoate} was applied preemergence at 1.4 + 0.168 + 0.035 kg ai ha^{-1}. Quizalofop-p {(R)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy] propanoic acid} + acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]2-nitrobenzoic acid} was also applied to V4 soybean at 0.062 + 0.42 kg ai ha^{-1}, respectively, in order to control escaped weeds from the 1999 preemergence application. Additional weed control was done by hand in all years.

Experimental design was a randomized complete block with four replications. Treatments were a factorial arrangement of four B rates and two application timings. The B source for this experiment was soluble disodium octaborate tetrahydrate, sold under the commercial trade name Solubor (U.S. Borax, Valencia, California), dissolved in 94.5 L ha^{-1} of water and applied broadcast at rates of 0, 140, 280, or 560 g ha^{-1} to R3 or R5 soybean. Foliar applications were made utilizing a CO_2 backpack with a 2 m boom, having four 8004VS flat-fan nozzles spaced 46 cm apart, and calibrated to deliver 234 L ha^{-1}. The four nozzles were aligned with the four plot rows, enabling the researcher to walk between plots while making applications.

The center two rows were harvested with a small plot combine equipped with a scale, moisture tester, and a data logger. Yields were adjusted to 13% moisture for all plots. Sub-samples of each plot were obtained to determine seed weight and quality. Data were subjected to analysis of variance using the standard least squares procedures of JMP v. 3.2.1 by SAS (SAS Inst. 1996).

RESULTS AND DISCUSSION

Barlett's test for homogeneity rejected the hypothesis that the means between years were equal, indicating heterogeneity of variance (p=0.11); thus data have been presented by year. Correspondingly, a Welch analysis of variance testing that year means were equal was rejected (p<.0001). The mean soybean yields for 1997, 1998, and 1999 were 3470 (SE=38.8), 5060 (SE=65.0), and 2920 (SE=148.8) kg/ha, respectively. Within each year, analysis of variance indicates no significant difference between any B rate at any stage of application (Table 3). Yield data for the 0.28 kg/ha rate at the R5 application in1999 are not shown, due to a poor stand in the experimental plots.

The variance in the yields can be attributed to soil type, environmental differences, and cropping system. With respect to moisture in 1998, the soil profile was brought up to field capacity after planting and maintained there via daily irrigation using the sub-surface micro-drip irrigation system. However, in 1997, due to limited irrigation reserves and prolonged lack of rainfall the field was only maintained at field capacity until the R6 development stage, probably causing some of the reduction in yields when compared to 1998. In contrast, the lowest average yields were experienced in 1999, primarily due to a completely dry soil profile to a 91-cm depth at planting that could not be recharged during the growing season with the center pivot irrigation, due to low rainfall and low irrigation reserves. These less than optimum moisture levels in 1999 and 1997 could be largely responsible for the lower yields when compared to 1998 where optimum water was maintained at all times.

With respect to cultural practices, planting date in 1999 was later than the planting dates in either 1997 or 1998. However, the late planting date is not likely the reason for the lower yield; planting date in 1999 was only about 20 days later than the other years, and plant populations were adjusted upwards as suggested by Virginia soybean production guidelines (Holshouser, 1998). Regardless, the differences allowed for three different yield potentials in which to test the effect of B on soybean yields.

Leaf tissue samples were taken from the uppermost expanded leaves from random locations within the experiment at the R1 growth stage. Tissue analysis indicated 45, 63, and 67 mg kg^{-1} B in 1997, 1998, and 1999, respectively. These concentrations fall above the minimum concentration of 10 mg kg^{-1} B required by soybean for maximum, non-boron limited yields (Gupta, 1993).

Seed weight data, based on weight of 100 seeds, indicates significant differences between years, but no treatment effects on seed weight were observed within any year, as indicated by analysis of variance. Seed weight averages for 1997, 1998 and 1999 are 17.61, 16.66, and 15.10 g per 100 seeds, respectively.

This lack of response to B is in agreement with the research of Reinbott and Blevins (1995) who reported no response to a foliar boron applications totaling 1.12 kg ha^{-1} B applied at four times over the growing season, each time at a rate of 0.28 kg ha^{-1} B. Their first application was made at full flowering (R2) and the next at R3, R4, and R5 stages of plant growth. The researchers noted leaf burning as a possible cause for eliminating yield benefits of B with four applications. Yield benefits were seen when 0.56 kg ha^{-1} B was applied in two split applications at the R4 and R5 stages. However, we observed no leaf burning at any B rate, and had average soil test B levels seven times lower than those of Reinbott and Blevins, and still no yield response to B existed.

Touchton and Boswell (1975) also reported no response to foliar applications of B at first bloom and one week after bloom at one of two sites. At the second site Touchton and Boswell found 4% yield increase, but this increase may have been due to a low initial soil B concentration (0.14 ppm) determined by the hot water soluble method (HWS—curcumin method).

Lack of response to B applications could originate from high B levels in the soil or incorrect timing of B applications. However, in our experiment soil test B levels were relatively low, and B application timing was similar to work by various authors (Schon and Blevins, 1987; Shcon and Blevins, 1990; Hudson and Clarke, 1997), as well as suggested by industry (U.S. Borax Pub. 296194).

CONCLUSIONS

Previous research with B applications to soybean was inconsistent and variable. However, these data revealed a consistent lack of soybean yield response to reproductive stage B applications annually. Furthermore, this research encompassed three significantly different yield potentials over three years and no response to B fertilization was seen at any B rate, time of application, or yield level.

Native soil B levels of 0.1 to 0.2 ppm as determined by the Mehlich I extraction appeared to be adequate to achieve high yields in non-drought stressed soybean production systems in the coastal plain soils of the Mid-Atlantic growing region. This was validated by tissue analysis showing B content within or above the sufficiency range set forward for soybean production (Gupta, 1993). In summary, the B fertilization of nodulating soybean had no significant yield effect at yield environments ranging from 3300 to 5300 kg ha^{-1}.

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Table 1. Selected chemical properties for soil utilized in the 1997-1999 boron experiment 1997-1999.

Year	Depth	CEC†	pH	OM‡	N§	P¶	K#	Mg#	Ca#	B††	Mn‡‡	Zn§§
	cm	cmol kg^{-1}		%	------------------------------ mg kg^{-1} ------------------------------							
1997	0-15	Na¶¶	6.4	2.5	na	16	103	50	492	0.2	2	0.4
1998	0-15	4.3	5.8	1.2	30	63	98	61	467	0.1	12	4
	15-31	5.4	5.7	1.0	32	75	99	48	471	0.1	14	5
	31-61	3.3	5.3	0.7	17	17	83	37	318	0.1	5	2
	61-94	4.5	4.7	0.1	25	9	71	58	292	0.1	5	2
1999	0-15	7.3	6.5	1.2	16	76	237	188	712	0.2	78	17
	15-31	3.6	6.4	1.0	13	72	186	119	421	0.1	73	19
	31-61	3.3	6.4	0.7	8	23	96	120	405	0.1	32	4
	61-94	5.1	6.5	0.6	8	13	108	154	487	0.1	18	5

†--CEC, Cation exchange capacity, as determined by summation of cations

‡--OM, Organic matter, as determined by the Walkley-Black method in all years

§--N, Nitrogen comprised of $NH_4^+ + NO_3^-$

¶--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined by Bray P1 extraction

#--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined by 1NAoAc extraction

††--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined as hot water soluble

‡‡--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 by Mehlich III extraction

§§--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 by 0.1N HCl

¶¶--Not available

Table 2. Nutrient content of the uppermost fully expanded leaves at R2 stage prior to B application.

Year	N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al
	----------	----------	----------	----------	----------	----------	g kg^{-1}	----------	----------	----------	----------	----------	----------
1997	**na†**	**2.7**	**3.5**	**25.8**	**3.5**	**7.8**	**0.1**	**0.045**	**0.028**	**0.023**	**0.096**	**0.011**	**0.052**
1998	**55**	**3.8**	**6**	**28.3**	**5.3**	**9.8**	**0.3**	**0.063**	**0.081**	**0.065**	**0.169**	**0.021**	**0.077**
1999	**51.8**	**3.3**	**3.9**	**25.7**	**4.5**	**10.2**	**0.4**	**0.067**	**0.046**	**0.097**	**0.106**	**0.007**	**0.125**

†--na, Not available

Table 3. Mean soybean yields over three years with four B rates at two stages of plant growth.

	Soybean grain yields					
	1997		1998		1999	
Boron Applied	R3†	R5‡	R3	R5	R3	R5
------kg ha^{-1}------	----------------------------kg ha^{-1}----------------------------					
0	3316	3489	4950	5178	2844	3153
0.14	3546	3461	4859	5026	2862	3055
0.28	3439	3670	5153	5012	3169	----
0.56	3458	3408	5322	4914	2985	3245
LSD	NS	NS	NS	NS	NS	NS

†-- R3 stage, beginning pod formation

‡--R5 stage, beginning seed formation

Chapter 3—Soybean Yield Response to Reproductive Stage Nitrogen Applications

ABSTRACT:

The yield response of soybean [*Glycine Max* (L.) Merr.] to nitrogen (N) fertilization has been inconsistent. This research examined the effect of reproductive stage nitrogen applications on soybean yields over a three year period in the coastal plain region of Virginia. Treatments were a factorial arrangement of seven N rates (0, 56, 84, 112, and 168 kg ha^{-1} in 1997 and 0, 28, 56, 84, 112, and 168 kg ha^{-1} in 1998 and 1999) utilizing 30% UAN dribbled beside the rows to prevent leaf burn, applied at either the R3 or R5 growth stage. Plots were irrigated to prevent drought stress. Applications of N did not increase yield at any rate or stage, regardless of year or yield potential. The lack of response to supplemental N suggests that N supplied via fixation and soil organic matter mineralization is adequate for high yields in the coastal plain production region of Virginia.

Soybean Yield Response to Reproductive Stage Nitrogen Applications

Soybean demand for nitrogen (N) can exceed 2.5 kg N bu^{-1} for optimum seed yield (Flannery, 1986). Utilization of the majority of this N occurs during seed development, and it is at this time that the soybean begins to remobilize tissue N for translocation to the seed. Nitrogen sources for the soybean include mineralization, soil organic matter, symbiotically fixed N, and N incorporated into plant tissue. Under certain soil, climatic, and yield conditions, N supply may limit soybean seed production. However, N applications made before reproductive growth stages are reported to decrease *Bradyrhizobia* activity, exhibited by reduced growth of nodules and lower N fixation, thus further increasing the difference between N supply and demand (Yoneyama, et al., 1985; Bhangoo and Albritton, 1976; Ham, et al., 1975; Yoshida, 1979). Laboratory research has demonstrated that as N applications increase, nodule fresh weight and haemoglobin content of nodules decreases when compared to a control, denoting a lowered amount of N fixation (Harper and Cooper, 1971).

Field studies to measure soybean response to applied N have been conducted by several researchers. Preplant applied N at 134 kg ha^{-1} on a silt loam soil in Nebraska to irrigated soybeans did not consistently alter yield (Slater, et al., 1991). Similarly, on a silty clay loam in Illinois N applications from 0 to 900 kg ha^{-1} yr^{-1} elicited no yield effect, except for slight yield reductions at the higher N rates (Welch, et al., 1973). Two sites in Michigan generated variable results. On a Zilwaukee clay no yield response was reported at an N rate of 134 kg ha^{-1}, while on a sandy loam yield increases averaged 460 kg ha^{-1} over the control plots (Hesterman and Isleib, 1991).

One solution for overcoming this situation of supplying needed N for plant growth without impeding the development of *Bradyrhizobium* is foliar N applications during reproductive stages of plant growth. Yield increases from foliar fertilization using fertilizer grade urea applied at rates of 45, 90, and 135 kg ha^{-1} at R4 (Fehr and Caviness, 1977) were reported (Syverud, et al., 1980). Increases over the control yield of 2640 kg ha^{-1} for the two years averaged 123, 160, and 243 kg ha^{-1} for the three treatments, respectively. In a series of experiments conducted at eight sites over a 2-yr period on irrigated soybean, applications of N at 22 and 44 kg ha^{-1} increased yield at six of the eight sites for an average increase of 464 kg ha^{-1} or 11.8% (Wesley, et al., 1998). Yields at the two unresponsive sites were less than 3360 kg ha^{-1} and the authors suggested that responses from N might only be realized under high yield potentials.

Similarly, greenhouse and field studies by Yoshida (1979) reported yield increases with N applications. The greenhouse study utilized five N rates from 15 to 150 ppm NO_3^--N in complete hydroponic solutions and a control containing no N. Total seed yield increased from the control of 0.9 g to 81.6 g per pot with 50 ppm N, while the highest N rate, 150 ppm, yielded 76.7 g per pot. In the field study, N applications from 30 to 90 kg ha^{-1} applied from seedling emergence to R1 increased yields by 720 kg ha^{-1}, averaged across all treatments. Yield benefits of up to 148 kg ha^{-1} over the control of 2856 kg ha^{-1} have been reported in Kentucky. In this work, liquid UAN (28% N) was dribbled beside the rows between the R2 to R3 development stages at rates of 29 kg ha^{-1} and 36 kg ha^{-1} in 1996 and 1997, respectively (Judy and Murdock, 1998).

Supplemental N has been thought to be beneficial only in years of adequate moisture (Keogh, et al., 1979) or under irrigation at high yield potentials (Wesley et al., 1998).

However, experiments have demonstrated that supplemental N will increase yields in plants under drought stress. When water stress occurs during the critical time of seed filling, carbon and N can be remobilized from plant leaf tissue and translocated to the seeds, resulting in faster declines in photosynthetic rates (De Souza, et al., 1997). This leads to premature leaf senescence, and lowered yields through reduced seed size and seed number. Observed yield increases in Arkansas on a silt loam soil occurred where non-irrigated soybeans received a broadcast N application rate of 224 kg ha^{-1} at V6 and an additional 112 kg ha^{-1} N application at R2. Yield for non-irrigated soybeans without N application was 2373 kg ha^{-1}, while yield for the non-irrigated soybeans with N applications was 2798 kg ha^{-1}. The yield for the irrigated soybeans which received no N application was 2728 kg ha^{-1}, and the difference between the non-irrigated soybeans receiving N and the irrigated soybeans not receiving N were not significantly different (Purcell and King, 1996). These researchers concluded that the application of N fertilizer alleviated the N deficit due to poor N fixation by *Bradyrhizobium* caused by low soil moisture. In an additional greenhouse experiment, Purcell and King (1996) also observed that through supplemental N fertilization, the effects of drought were partially reversed when compared to plants which received full water and no additional N, since the N application compensated for the low N fixation of the *Bradyrhizobium.*

Supplemental late season N applications offer the potential benefits of increasing yield under optimum moisture conditions as well as during times of inadequate moisture. Proper application timing, rate of application, and the conditions necessary for yield responses have not been fully determined for the Mid-Atlantic United States. The objective of this experiment was to determine the yield effects of N applications at different rates and growth stages on soybean seed yield on sandy Coastal Plain soils of the Mid-Atlantic soybean-growing region.

MATERIALS AND METHODS

Deltapine soybean cultivar DP 3478 was planted in mid-May at a population of 263,000 and 272,000 plants/ha in 1997 and 1998, respectively on a Nansemond fine sandy loam (coarse-loamy, siliceous, thermic, Aquic Hapludult) in Suffolk, Virginia. In 1999, soybeans were planted in mid-June at a population of 432,250 plants/ha in a State fine sandy loam (fine-loamy, mixed, semiactive, thermic Typic Hapludult) near Mt. Holly, Virginia, following barley harvest. The increase in plant population in the Mt. Holly location follows Virginia Cooperative Extension recommendations for late planting after small grain harvest (Holshouser, 1998). Plot size was four 46-cm wide rows by 7.3 m long each year. To prevent moisture stress, plots were irrigated, utilizing sub-surface micro-drip irrigation in 1997 and 1998 and an overhead center pivot system in 1999. In 1997, soil samples were taken to a depth of 15 cm prior to planting and tested for available nutrients (Table 1). In 1998 and 1999, soil samples were taken at emergence at depths of 0-15, 15-31, 31-61, 61-91 cm and tested for available nutrients (Table 1). Plant tissue samples comprised of the uppermost fully expanded leaves were taken randomly at R1 and analyzed for nutrient content (Table 2). In 1997, both P_2O_5 and K_2O were applied at 45 kg ha^{-1} before planting. No fertilizer application occurred in 1998, since soil test results indicated no additional fertilizer needed. In 1999, 67.2 kg ha^{-1} P_2O_5 and 112 kg ha^{-1} K_2O were applied prior to barley planting.

In 1997-1998 metolachlor {2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide} + metribuzin {4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-

1,2,4-triazin-5(4H)-one} was applied preemergence at 1.4 + 0.25 kg ai ha^{-1}, respectively. In 1999, metolachlor + sulfentraxone {N-[2,4-dicloro-5-[4-difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide} + chlorimuron-ethyl {ethyl 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoate}, was applied preemergence at 1.4 + 0.168 + 0.035 kg ai ha^{-1}. Quizalofop-p {(R)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy]propanoic acid} + acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]2-nitrobenzoic acid} was also applied to V4 soybean at 0.062 + 0.42 kg ai ha^{-1}, respectively, in order to control escaped weeds from the 1999 preemergence application. Additional weed control was done by hand in all years.

Experimental design was a randomized complete block with four replications. Treatments were a factorial arrangement of seven N rates and two application timings. In 1997, N as a 30% urea ammonium nitrate (UAN) solution was applied at 0, 28, 56, 84, 112, and 168 kg ha^{-1} to plots at either the R3 or R5 growth stage. In 1998 and 1999, N was applied at 0, 14, 28, 56, 84, 112, 168 kg ha^{-1} to plots at either the R3 or R5 growth stage. Applications were made with a CO_2 backpack with a single nozzle wand and a length of hose to place the N below the canopy, which prevented leaf burn. The pressure and nozzle size were adjusted to deliver the appropriate rate. The applications were made between the first and second row and third and fourth row, allowing equal distribution of N to all rows. Adequate rain fell within seven days after each application, minimizing potential volatilization. In 1999, N-[n-butyl] thophosphoric triamide, a urease inhibitor sold under the trade name Agrotain (IMC-Agrico, Bannockburn, IL), was added to the N solution to prevent volatilization if irrigation was delayed; however, the plots were irrigated two days after N application.

The center two rows were harvested with a small plot combine equipped with a scale, moisture tester, and a data logger. Yields were adjusted to 13% moisture for all plots. Sub-samples of each plot were obtained to determine seed weight and quality. Data were subjected to analysis of variance using the standard least squares procedures of JMP v. 3.2.1 by SAS (SAS Inst. 1996).

RESULTS AND DISCUSSION

Bartlett's test for homogeneity rejected the hypothesis that the means between years were equal, indicating heterogeneity of variance ($p>0.1$); thus, data are presented by year. Correspondingly, a Welch analysis of variance testing that year means were equal was rejected ($p<.0001$). The mean soybean yields for 1997, 1998, and 1999 were 3600 (SE=10.50), 5160 (SE=156.2), and 2450 (SE=72.4) kg ha^{-1}, respectively. Within each year, analysis of variance indicates no significant difference between any N rate at any stage of application (Table 2).

The variance in the yields can be attributed to soil type, environmental differences, and cropping system. With respect to moisture in 1998, the soil profile was brought up to field capacity after planting and maintained there via daily irrigation using the sub-surface micro-drip irrigation system. However, in 1997, due to limited irrigation reserves and prolonged lack of rainfall the field was only maintained at field capacity until the R6 development stage, probably causing some of the reduction in yields when compared to 1998. In contrast, the lower yields experienced in 1999 were primarily due to a completely dry soil profile to a 91-cm depth at planting that could not be brought to field capacity during the growing season with the center pivot irrigation due to low rainfall and low irrigation reserves. However, the soybean crop was never visually under severe moisture stress during the season. These less than optimum moisture levels in 1997 and 1999 could be largely responsible for the reduced yields when compared to the 1998 yield levels where optimum water was maintained at all times.

With respect to cultural practices, planting date in 1999 was later than the planting dates in either 1997 or 1998. However, the late planting date is not likely the reason for the lower yields; planting date in 1999 was only about 20 days later than the other years, and plant populations were adjusted upwards as suggested by Virginia soybean production guidelines (Holshouser, 1998). Regardless, the differences allowed for three different yield potentials in which to test the effect of N on soybean.

Leaf tissue samples were taken from uppermost expanded leaves from random locations within the experiment at R1. Tissue analysis (Table 3) indicated 53.4 and 53.9 g kg^{-1} N in 1998 and 1999, respectively. These concentrations fall within the sufficiency ranges of 40.0 to 55.0 g kg^{-1} N concentration required by soybean for maximum, non-nitrogen limited, yields (Mills and Jones, 1996). The tissue analysis for N was not performed in 1997.

Seed weight data, based on weight of 100 seeds, indicates significant differences between years, but no treatment effects on seed weight within in any year, indicated by analysis of variance. Averages for 1997, 1998, and 1999 are 17.61, 16.60, and 14.83 g per 100 seeds, respectively.

This lack of response is in agreement with work by Purcell and King (1996) who observed no response to N under irrigated conditions on a silt loam soil to two applications of N at the V6 stage and the R2 stage. This lack of yield response to treatments also agrees with work by Haq and Mallarino (2000). These researchers reported inconsistent yield responses to foliar fertilization with N-P-K nutrient solutions applied at the V5 development stage over 27 sites. The data is also consistent with work by Beard and Hoover (1971), Poole et al. (1983), Weber (1966), Cooper and Jeffers (1984), Reese and Buss (1992) and Slater, et al.(1991). The lack of response in these experiments indicates that N supplied from soil organic matter mineralization and fixation via *Bradyrhizobium* is adequate to meet soybean requirements at yield levels up to 5600 kg ha^{-1}.

CONCLUSIONS

Previous research with N applications to soybean was inconsistent and variable. However, these data revealed a consistent lack of soybean yield response to reproductive stage N applications annually. Furthermore, this research encompassed three significantly different yield potentials over three years and no response to N fertilization was observed for any N rate, time of application, or yield level.

Nitrogen from N-fixation and soil reserves appears to be adequate to achieve high yields in non-drought stressed soybean production systems of the Coastal Plain soils of the Mid-Atlantic growing region. Tissue analysis of N content were within the sufficiency range set forward for soybean production (Mills and Jones, 1996), and the N fertilization of nodulating soybean had no significant yield effect in yield environments ranging from levels 2400 to 5100 kg ha^{-1}.

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Table 1. Selected chemical properties for soils utilized in the 1997-1999 nitrogen experiment.

Year	Depth	CEC†	pH	OM‡	N§	P¶	K#	Mg#	Ca#	B††	Mn‡‡	Zn§§
	cm	cmol kg^{-1}		%	----------------------------			mg kg^{-1}	----------------------------			
1997	0-15	na¶¶	6.6	2.1	Na	13	116	48	504	0.3	1.9	0.6
1998	0-15	3.6	6.5	0.7	23	61	49	78	411	0.1	14	6
	15-31	3.0	5.9	0.3	19	58	46	42	275	0.1	10	6
	31-61	1.9	5.6	0.7	14	26	82	34	291	0.1	6	3
	61-94	4.1	4.9	0.5	17	11	70	38	236	0.1	1	2
1999	0-15	4.3	6.5	1.2	13	69	180	117	381	0.1	71	19
	15-31	2.5	6.4	0.9	10	54	98	88	313	0.1	63	11
	31-61	4.0	6.5	0.8	8	42	113	106	392	0.1	59	6
	61-94	3.9	6.5	1.1	8	17	103	117	359	0.1	41	3

†--CEC, cation exchange capacity, as determined by summation of cations

‡--OM, organic matter, as determined by the Walkley-Black method in all years

§--N, nitrogen, comprised of $NH_4^+ + NO_3^-$

¶--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined by Bray P1 extraction

#--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined by 1NAoAc extraction

††--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined as hot water soluble

‡‡--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 by Mehlich III extraction

§§--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 by 0.1N HCl

¶¶--Not available

Table 2. Mean soybean yields over three years with seven N rates at two stages of plant growth.

	Soybean grain yields					
	1997		1998		1999	
Nitrogen Applied	**R3**	**R5**	**R3**	**R5**	**R3**	**R5**
------kg ha^{-1}------	---------------------------kg ha^{-1}---------------------------					
0	**3455**	**3677**	**4797**	**5046**	**2328**	**2662**
14	**--†**	**--†**	**4966**	**5324**	**2666**	**2286**
28	**3554**	**3443**	**4538**	**5672**	**2570**	**2415**
56	**3747**	**3430**	**5611**	**4966**	**2293**	**2609**
84	**3535**	**3806**	**5143**	**5039**	**2301**	**2316**
112	**3551**	**3575**	**5283**	**5105**	**2726**	**2221**
168	**3704**	**3444**	**5578**	**5218**	**2840**	**2063**
LSD	**NS‡**	**NS**	**NS**	**NS**	**NS**	**NS**

†--The 14 kg ha^{-1} N rate was not utilized in 1997

‡--NS, no significance

Table 3. Nutrient content of the uppermost fully expanded leaves at R2 stage prior to N application.

Year	N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al
	---						g kg^{-1}					---	
1997	**na†**	**2.5**	**2.3**	**23.9**	**3**	**7.7**	**0.1**	**0.044**	**0.022**	**0.019**	**0.126**	**0.011**	**0.137**
1998	**53.9**	**3.6**	**7**	**23.5**	**5.7**	**8.6**	**0.1**	**0.051**	**0.078**	**0.058**	**0.189**	**0.02**	**0.095**
1999	**53.4**	**3.4**	**4.5**	**27.7**	**4.8**	**10.9**	**0.5**	**0.066**	**0.051**	**0.103**	**0.103**	**0.006**	**0.049**

†--Not Available

Chapter 4—Soybean Yield Response to Nitrogen and Boron Applications: Influence of Cultivar, Row Spacing, Irrigation, and Planting Date

ABSTRACT:

The yield response of soybean [*Glycine Max* L. Merr.] to applications of nitrogen (N) or boron (B) have been inconsistent. Little research investigating yield effects of N and B combinations in the Mid-Atlantic region is available. The first experiment in this research investigated the effect of reproductive stage N and B applications on three soybean cultivars planted in two different row spacings in an irrigated field. The second experiment utilized two planting dates and a sub-surface micro-drip irrigation system designed to supplement natural rainfall to create four irrigation regimes (100% plant required moisture, 66%, 33%, and 0% supplemental moisture). In the second experiment, moisture regimes were established in 1998, but eliminated due to late season rains, and in 1999 above average rainfall prevented the possibility of establishing any moisture gradients. Nitrogen applications were made at the R3 development stage, utilizing 30% UAN, dribbled next to the row and the B applications were formulated with disodium octaborate tetrahydrate dissolved in 94.5 L ha^{-1} of water applied foliarly via a CO_2 backpack. Treatments in both experiments were either 0 N and 0 B; 56 kg ha $^{-1}$ N, and 0 B; 0 N and .28 kg ha^{-1} B; or 56 kg ha^{-1} N and 0.28 kg ha^{-1} B, all applied at he R3 stage. Analysis of variance indicated no response to any N and B treatment in any year, regardless of cultivar, row spacing, planting date, or moisture level. The lack of response to N and B treatments indicates that native soil B levels and N from mineralization and

fixation are adequate for high yields (>5000 kg ha^{-1}) in the Mid-Atlantic soybean production region.

Soybean Yield Response to Nitrogen and Boron Applications: Influence of Cultivar, Row Spacing, Irrigation, and Planting Date

Soybean plants require 16 nutrients for plant growth and seed production (Mengel, et al., 1987). However, as average yields increase, the requirements that were considered adequate for lower yields may be limiting plant growth and optimum seed yields. Macronutrient research has shown that supplemental applications of nitrogen (N) have boosted seed yields in some studies (Wesley, et al., 1998; Purcell and King, 1996; Syverud et al., 1980; Garcia and Hanway, 1976). Similarly, applications of the micronutrient boron (B) have been reported to improve soybean seed yields (Reinbott and Blevins, 1995; Schon and Blevins, 1990; Touchton and Boswell, 1975; Gascho and McPherson, 1997). Although these elements have been studied separately in other regions, data is unavailable for the Mid-Atlantic region. Also, data is unavailable for combined applications of these elements.

Soybean plants require relatively large amounts of nitrogen (N) for optimum seed production, possibly exceeding 90 g N per kg seed produced (Flannery, 1986). With such a high N requirement, it is possible that under certain environmental and climatic yield conditions, N supply could be limiting optimum seed production. Soybeans utilize N from several sources, including mineralization, soil organic matter, symbiotically fixed N, and N incorporated into plant tissue. Demand for seed N is highest from the R5 to R8 soybean development stage as defined by Fehr and Caviness (1977). During this period, the plant utilizes N from all sources, but in the early to mid-pod fill stages, fixation by *Bradyrhizobia* decreases rapidly (Harper, 1987). The soybean plant compensates for this reduction in fixed N by utilizing N already incorporated in plant tissue, beginning in the

R6 growth stage (Harper, 1987). As N is remobilized from older plant tissue to the developing seeds, senescence of plant tissue begins. During this period, it is possible that under certain climatic conditions, such as high yield environments, the soybean plant may be unable to supply optimum N to the developing seeds. Supplying N to the soybean plant during the time of peak seed demand, may possibly supplement existing N resources, prevent premature senescence, and boost seed yields (Garcia and Hanway, 1976; Nelson et al., 1984; Salado-Navarro, et al., 1985; Sinclair and DeWhit, 1976).

However, N applied prior to the reproductive stages of development generally reduces the activity of *Bradyrhizobia*, exhibited by decreased nodule growth and poor N fixation (Yoneyama, et al., 1985; Bhangoo and Albritton, 1976; Ham, et al., 1975; Yoshida, 1979; Beard and Hoover, 1971). This situation only exacerbates the difference between N supply and N demand, and is illustrated by the work of several researchers who reported no yield improvement with preplant N applications (Slater, et al., 1991; Welch, et al., 1973; Hesterman and Isleib, 1991). A possible solution to overcoming this situation of supplying needed N without reducing the fixation capacity of *Bradyrhizobia*, is via N applications made during reproductive growth stages, applied either foliarly or to the soil.

Nitrogen applied to the foliage at rates of 45, 90, and 135 kg ha^{-1} to R4 soybean increased yield over the control of 2640 kg ha^{-1} by 123, 160, and 243 kg ha^{-1}, respectively (Syverud, 1980). Garcia and Hanway (1976) reported yield increases from foliar applications of various nutrient solutions. Yield increases of 130 kg ha^{-1} over the control yield of 2290 kg ha^{-1} were observed when a total of 34 kg ha^{-1} N was applied in two applications at the R4 and R5 stages of development. Similarly, a yield increase of 220 kg ha^{-1} over the control yield of 2270 kg ha^{-1} was obtained when a total of 34 kg ha^{-1} N was applied at the R5 and R6 stages (Garcia and Hanway, 1976). In a series of experiments conducted at eight sites over a 2-yr period on irrigated soybean, foliar applications rates of N at 22 and 44 kg ha^{-1} increased yield at six of the eight sites for an average increase of 464 kg ha^{-1} or 11.8% (Wesley, et al., 1998). At the two sites that were unresponsive, soybean yields averaged less than 3360 kg ha^{-1} and the authors suggested that responses from N might only be realized under high yield potentials.

In a two-year experiment, yield increased an average of 148 kg ha^{-1} over the control of 2860 kg ha^{-1} when N was applied to the soil as 28% urea ammonium nitrate (UAN) (Judy and Murdock, 1998). In this research, N was dribbled beside the rows to R2-R3 soybean at rates of 29 kg ha^{-1} in 1996 and at a rate of 36 kg ha^{-1} in 1997. In Arkansas, a broadcast rate of 224 kg ha^{-1} N as NH_4NO_3 at the V6 stage and an additional 112 kg ha^{-1} at R2 increased yield by 425 kg ha^{-1} over a control yield of 2373 kg ha^{-1} under dryland conditions (Purcell and King, 1996). Early research from Illinois also indicated an average yield increase of 485 kg ha^{-1} over the control yield of 817 kg ha^{-1} (Lyons and Earley, 1952). In this non-irrigated experiment in a dry year, NH_4NO_3 was sidedressed and incorporated at the “mid-bloom” stage (42 days after emergence) using seven N rates from 0 to 672 kg ha^{-1}.

Similar to these yield benefits from reproductive stage N applications, yield enhancements have been reported from B applied during reproductive stages. Boron’s widespread role within the plant includes cell wall synthesis, sugar transport, cell division, differentiation, membrane functioning, root elongation, and regulation of plant hormone levels (Marschner, 1995; Romheld and Marschner, 1991; Pilbeam and Kirkby, 1983). While the importance of B for seed production is acknowledged, it is also recognized as one of the most commonly deficient micronutrients in agriculture, with reports of deficiencies in 132 crops in 80 countries (Shorrocks, 1997). Deficiencies typically result from boron leaching occurring in humid areas with coarse textured soils (Mortvedt and Woodruff, 1993; Marschner, 1995; Welch, et al., 1991).

On a Mexico silt loam soil in Missouri, two foliar applications of B at R1 and R2 increased the number of pods per branch (Schon and Blevins, 1990). These researchers also observed increases in both the number of pods per branch and the number of branches per plant when six split applications of B from R1 through R8 were applied. Two foliar applications at R4 and R5 totaling 0.56 kg ha^{-1} caused a yield increase of 356 kg ha^{-1} on a Mexico silt loam in Missouri (Reinbott and Blevins, 1995). Touchton and Boswell (1975) observed a four percent yield increase over control plots on a loamy sand testing low in hot water soluble (HWS) boron (0.14 ppm) when B was applied at 0.28, 0.56, and 1.12 kg ha^{-1} as two split applications, each at ½ the treatment rate with the first at R1 and the second application made seven days later.

On an irrigated Bonifay sand in Georgia, an application of 0.28 kg ha^{-1} B at R1 generated yields averaging 353 kg ha^{-1} higher than the control yield of 3247 kg ha^{-1} when averaged over five cultivars at the same site (Gascho and McPherson, 1997). In this study, three out of five cultivars showed significant response to B applications at any rate, leading the authors to believe that yield response to B may depend on cultivar. Other research from Georgia has investigated foliar B applications made in combination with diflubenzuron insecticide. Researchers reported an average yield increase of 23% at four sites (Hudson and Clarke, 1997). Untreated check plots averaged 2580 kg ha^{-1} while the B/diflubenzuron treated plots, applied at R2 to R3, yielded 3185 kg ha^{-1}.

Yield increases from a reproductive stage N application has been observed in research experiments. Similarly, higher yields have been achieved with applications of B made as foliar applications in the early reproductive stages of soybean development. However, little work has been done with both N and B applications to soybeans with the exception of research by Gascho (1992) on a loamy sand soil. That experiment utilized main plots of N, B, or N+B applied either via fertigation with a center pivot system, spray applications utilizing a tractor, and dribble applications made using a watering can. The B rate utilized was 0.45 kg ha^{-1} and the N rate was 45 kg ha^{-1}. Sub-plots in the experiment consisted of five different soybean cultivars. While no significant differences were found when all treatments and cultivars were averaged together, significant treatment effects on yields did exist when cultivars were examined individually. With one cultivar, fertigation applications of N+B at R5 generated total dry matter yields 5978 kg ha^{-1} higher than control yields of 9149 kg/ha^{-1}. For another cultivar, spray applications of N and B made at R5 increased seed yield by 470 kg ha^{-1} over the control yield of 2889 kg ha^{-1}.

These results demonstrate the need for research on the yield effects of late season N and B combinations to soybeans. The objectives of this research were: 1) to determine the effect of cultivar and row spacing on the response of irrigated, full-season soybean to R3-stage N and B applications; and 2) to determine the effect of irrigation level on the response of full-season and double-crop soybean to R3-stage N and B applications.

MATERIALS AND METHODS:

Cultivar and Row Spacing Effects

In 1997, soybean cultivars Graham and Hutcheson were planted on May 23 at a population of 260,000 plants ha^{-1} on a Nansemond fine sandy loam (coarse-loamy, siliceous, thermic, Aquic Hapludult). In 1998, soybean cultivars Terra TS 415, Deltapine DP 3478, and Holladay were planted on May 17 at a population of 272,000 plants ha^{-1} on a Nansemond fine sandy loam, and in 1999 the same cultivars as 1998 were planted on a State fine sandy loam (fine loamy, mixed, semiactive, thermic Typic Hapludult) at a population of 422,000 plants ha^{-1}. Soybeans were planted following barley (*Hordeum vulgare* L.) harvest in 1999, therefore plant populations were increased in accordance with Virginia Cooperative Extension recommendations for double crop planting (Holshouser, 1998). Plot size was four 46-cm rows or seven 23-cm rows by 7.3 m long. To prevent moisture stress, experiments were irrigated using sub-surface micro-drip irrigation in 1997 and 1998 and an overhead center pivot system in 1999. In 1997, 15-cm deep soil samples were taken at planting and tested for available nutrients (Table 1). In 1998 and 1999, soil samples were taken from depths of 0-15, 15-31, 31-61, 61-91 cm and tested for available nutrients (Table 1). Plant tissue samples of the uppermost fully expanded leaves were taken randomly at R1, before treatment application, and analyzed for nutrient content (Table 2). In 1997, both P_2O_5 and K_2O were applied at 45 kg ha^{-1} before planting and before soil samples were taken. No fertilizer was applied in 1998, as nutrient levels were adequate for high yields. In 1999, 67.2 kg ha^{-1} P_2O_5 and 112 kg ha^{-1} K_2O were applied prior to barley seeding.

In 1997 and 1998, metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide] + metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one] was applied preemergence at 1.4 + 0.28 kg ai ha^{-1} , respectively. In 1999, metolachlor + sulfentraxone {N-[[2,4-dicloro-5-(4-difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide} + chlorimuron-ethyl {ethyl 2-[[[[(4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoate} was applied preemergence at 1.4 + 0.168 + 0.035 kg ai ha^{-1}. Quizalofop-p {(R)-2-[4-[(6-chloro-2-quinoxalinyl)oxy]phenoxy] propanoic acid} + acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]2-nitrobenzoic acid} was also applied to V4 soybean at 0.062 + 0.42 kg ai ha^{-1}, respectively, in order to control escaped weeds from the 1999 preemergence application. Any additional weed control was performed by hand in all years.

Experimental design was a split-split plot with four replications, utilizing cultivar as main plot, row spacing as subplots, and N and B treatment as the sub-subplot. Nitrogen and B treatments were: 1) 0 kg ha^{-1} N and 0 kg ha^{-1} B; 2) 0 kg ha^{-1} N and 0.28 kg ha^{-1} B; 3) 56 kg ha^{-1} N and 0 kg ha^{-1} B; and 4) 56 kg ha^{-1} N and 0.28 kg ha^{-1} B in all years. The B source utilized in this experiment was soluble disodium octaborate tetrahydrate, sold under the commercial trade name Solubor (U.S. Borax, Valencia, CA.), dissolved in 94.5 L ha^{-1} of water and applied at a rate of either 0 or 280 g ha^{-1} to R3 soybean. Foliar applications of B were made utilizing a CO_2 backpack with a 2 m boom, having four 8004VS flat-fan nozzles spaced 46 cm apart, and calibrated to deliver 234 l ha^{-1}. The four nozzles were aligned with the plot rows, enabling the researcher to walk between plots while making applications. The N source utilized in all years was 30% UAN solution, applied at either 0 or 56 kg ha^{-1} to plots at the R3 growth stage. Applications were made with a CO_2 backpack with a single nozzle wand and a length of hose to place the N solution on the soil below the canopy, preventing leaf burn. Adequate rain fell within seven days after each application in both 1997 and 1998, minimizing potential volatilization. In 1999, N-[n-butyl] thophosphoric triamide, a urease inhibitor sold under the trade name Agrotain (IMC-Agrico Company, Bannockburn, IL), was added to the N solution to prevent volatilization if irrigation was delayed; however, the plots were irrigated two days after N application.

The center two 46-cm rows or the center three 23-cm rows were harvested with a small plot combine equipped with a scale, moisture tester, and a data logger. Yields were adjusted to 13% moisture for all plots. Sub-samples of each plot were obtained to determine seed weight and quality. Data were subjected to analysis of variance using the standard least squares procedures of JMP v. 3.2.1 by SAS and means separated using Tukey's HSD procedures (SAS Inst. 1996).

Planting Date and Irrigation Level Effects

In 1998 Deltapine soybean cultivar DP 3478 was planted on May 14 and June 16 at populations of 296,000 and 346,000 plants ha^{-1}, respectively on a Eunola fine sandy loam (fine loamy, siliceous, semiactive, thermic Aquic Hapludult). In 1999, the same cultivar was planted in the same soil on May 19 and on July 6 following wheat (*Triticum aestivum* L. M. Thell) at populations of 252,000 and 467,000 plants ha^{-1}. All plant populations follow Virginia Cooperative Extension recommendations for soybean planting (Holshouser, 1998). Plot size was eight 46-cm wide rows by 9.1 m long. In

1998 and 1999, soil samples were taken to a depth of 18 cm and tested for available nutrients prior to planting and fertilizer application (Table 3). Plant tissue samples were taken randomly from the uppermost fully expanded leaves at R1, before treatment application and analyzed for nutrient content (Table 4). In 1998, 49 kg ha^{-1} P_2O_5, 100 kg ha^{-1} K_2O, 49 kg ha^{-1} SO_4^-, and 25 kg ha^{-1} Mg^{2+} were applied prior to planting. In 1999, 60 kg ha^{-1} P_2O_5 and 121 kg ha^{-1} K_2O were applied prior to planting.

A sub-surface micro-drip irrigation system that was designed to deliver four irrigation regimes, replicated three times was utilized in the experiment. However, due to the lack of a rainfall exclusion shelter, natural rainfall was present in all plots, and rainfall was accounted for in irrigation calculations. The irrigation regimes utilized were to simulate soil moisture levels that would deliver a goal of 0% supplemental water (natural rainfall only), 33% of plant required water, 66% of plant required water, and 100% of plant required water (Van Doren and Reicosky, 1987). Plant required water was defined as the amount of water required by the plant on a daily basis, adjusted for growth stage (Figure 1). This amount naturally increased as the season progressed, with more mature plants requiring higher amounts of irrigation to supplement rainfall. Soil moisture was measured using Watermark Soil Moisture Sensors (Irrometer Company, Riverside, CA) placed at depths of 31, 61, and 91 cm below the soil surface. These sensors are electrical resistance blocks made of a porous material (gypsum) and measure electrical conductivity within the block, which changes as the block equilibrates with the soil moisture (Hillel, 1998). Rainfall and soil moisture data are shown in Figures 2 and 3 and Table 5 gives approximate soil moisture levels corresponding to meter readings per the Irrometer Company instruction manual (1998, page 6). No sensor data is presented in

1999 as rainfall supplied 100% plant required water throughout the growing season, eliminating the need for supplemental irrigation. Rainfall data for 1998 and 1999 is presented in Figures 3 and 4, respectively.

The experiment was a split plot design with three replications, utilizing irrigation regime as the main plot and N and B treatments as the subplot. Nitrogen and B treatments, N and B sources, and application methods are the same as described in the cultivar and row spacing effect experiment. Weed control in 1998 for both planting dates consisted of a preemergence application of metolachlor + metribuzin + chlorimuron-ethyl applied at 1.68, 0.04, and 0.23 kg ai ha^{-1},respectivley. In 1999, for the first planting date, metolachlor + sulfentraxone + chlorimuron-ethyl was applied preemergence at 1.4 + 0.168 + 0.035 kg ai ha^{-1}, respectively. For the second planting date, metolachlor + sulfentraxone + chlorimuron-ethyl was applied preemergence at 1.4 + 0.168 + 0.035 kg ai ha^{-1}, respectively, and quizalofop-p was applied at 0.063 kg ai ha^{-1} to V4 soybean for additional control of escaped weeds.

The center six rows were harvested with a small plot combine equipped with a scale, moisture tester, and a data logger. Yields were adjusted to 13% moisture for all plots. Sub-samples of each plot were obtained to determine seed weight and quality. Data were subjected to analysis of variance using the standard least squares procedures of JMP v. 3.2.1 by SAS (SAS Inst. 1996).

RESULTS AND DISCUSSION

Cultivar and Row Spacing Effects

The 1997 data is presented separately from the 1998 and 1999 data due to a change in cultivars and number of cultivars planted. The mean soybean yield for 1997 was 3440

(S.E.=28.4) kg ha^{-1}. Within this year, analysis of variance indicated no effect of any N or B treatment, but did indicate significant cultivar effects and a significant cultivar by row spacing interaction. Yield of Hutcheson increased as row spacing decreased from 46 to 23 cm, but Graham exhibited no yield response to row spacing (Figure 6). Analysis of variance of the 1998 and 1999 data indicated that the years differed significantly; thus, data for these two years is presented separately. The mean soybean yields for 1998 and 1999 were 5120 (S.E.=75.8) and 2250 (S.E.=75.7) kg ha^{-1}, respectively (Figures 7 and 8). In both years, analysis of variance indicated no significant effect of N or B treatments. Similar to 1997, in 1998 there were significant effects of cultivar and a cultivar by row spacing interaction, while in 1999 cultivar was the only significant factor ($p<.0001$) (Figures 7 and 8).

The variance in the yields over years can be attributed to soil type, environmental differences, and cropping system. With respect to moisture in 1998, the soil profile was brought up to field capacity after planting and maintained there via daily irrigation using the sub-surface micro-drip irrigation system. However, in 1997, due to limited irrigation reserves and prolonged lack of rainfall the field was only maintained at field capacity until the R6 development stage, probably causing some of the reduction in yields when compared to 1998. The lower yields experienced in 1999 were primarily due to a completely dry soil profile to a 91-cm depth at planting that could not be brought to field capacity during the growing season with the center pivot irrigation due to low rainfall and low irrigation reserves. However, the soybean crop was never visually under severe moisture stress during the season. These less than optimum moisture levels in 1997 and

1999 are most likely the reason for the reduced yields when compared to the 1998 yield levels where water availability was optimum at all times.

With respect to cultural practices, planting date in 1999 was later than the planting dates in either 1997 or 1998. However, the late planting date is not likely the reason for the lower yield; planting date in 1999 was only about 20 days later than the other years, and plant populations were adjusted upwards as suggested by Virginia soybean production guidelines (Holshouser, 1998). Regardless, the differences allowed for three different yield potentials in which to test the effect of cultivar and row spacing effects on N and B applications on soybean yields.

Leaf tissue samples were taken randomly from the uppermost fully expanded leaves at R1. Tissue analysis (Table 2) indicated adequate levels of leaf N and B in 1998 and 1999. These concentrations fall within or above the sufficiency ranges of 40.0 to 55.0 g kg^{-1} N required by soybean for maximum, non-N limited yields (Mills and Jones, 1996). Similarly, the B concentration falls above the minimum required concentration of 10 mg kg^{-1} B required by soybean for maximum, non-boron limited, yields (Gupta, 1993). The tissue analysis for N was not performed in 1997.

Gascho (1992) observed a similar lack of response to N and B applications over cultivars and row spacings. Recent work by Haq and Mallarino (2000) from Iowa reported inconsistent yield responses to foliar fertilization of soybean at the V5 development stage with a N-P-K nutrient solution over 27 sites. In addition, no response to N applications has been reported by Beard and Hoover (1971), Poole et al. (1983), Weber (1966), Coopers and Jeffers (1984), Reese and Buss (1992) and Slater, et al.(1991). The lack of response in these experiments to N applications indicates that N supplied from soil reserves was adequate to meet soybean requirements at yield levels up to 5000 kg ha^{-1}. Furthermore, this lack of response to B applications is in agreement with work by of Reinbott and Blevins (1995) and Touchton and Boswell (1975). No response to B applications indicates that the B supplied from soil reserves is sufficient for yields over 5000 kg ha^{-1}.

Planting Date and Irrigation Level Effects

Due to the lack of irrigation treatments in 1999, the data for the planting date and irrigation level effects is presented by year and by planting date. In 1998, the irrigation system was utilized and four regimes were established (Figures 2 and 3). Increases in soil moisture readings correspond to rainfall events. These data demonstrated the ability to establish irrigation gradients using this system. However, the addition of rainfall exclusion shelters would be needed in order to remove rainfall effects. In 1998, analysis of variance indicated no significant effects of irrigation or N and B treatment differences at either planting date. Yields for the first and second planting dates, averaged over irrigation regime and treatment were 4530 (S.E.=88.7) and 3880 (S.E.=83.7) kg ha^{-1}, respectively. In 1999, the plots received rainfall in excess of the 100% of plant required water (Figure 5), eliminating the possibility of establishing different irrigation regimes. Thus, the four N and B treatments were replicated 12 times. Analysis of variance indicated no significant effect of any treatment, for either the first or second planting dates. In 1999, the first planting date had an average yield of 4450 (S.E.=80.8) kg ha^{-1} and the second planting date had an average yield of 2690 (S.E.=27.6) kg ha^{-1}. The lower yields from the second planting date in 1999 may be due to low light conditions and excessive rainfall from three hurricanes passing over the area during the month of September (Figure 5).

Leaf tissue samples were taken randomly from the uppermost expanded leaves at R1. Tissue analysis (Table 4) indicated adequate levels of leaf N and B in 1998 and 1999. These concentrations fall within or above the sufficiency ranges of 40.0 to 55.0 percent N required by soybean for maximum, non-N limited yields (Mills and Jones, 1996). Similarly, the B concentration falls above the minimum required concentration of 10 mg kg^{-1} B required by soybean for maximum, non-B limited yields (Gupta, 1993).

These results are consistent with work by Gascho (1992) who reported no significant effects of N and B applications when averaged over all cultivars, however Gascho did report some significant yield increases when each cultivar was examined individually. Further, Gascho (1992) summarizes that it is likely to see a response in high yielding situations, however in both years of my experiment, yields from the first planting dates averaged over 4500 kg ha^{-1} with no response to N and B applications.

CONCLUSIONS

Previous research with N applications or B applications to soybean was inconsistent and variable. However, these data reveal consistent results over three years. Furthermore, this research combined N and B applications during three years with different yield potentials, and no response to N or B fertilization was observed for any cultivar, row spacing, irrigation level, or planting date.

Native soil B levels of 0.1 to 0.2 ppm (HWS) and mineralized N combined with N from fixation by the soybean plant appear to be adequate to achieve high yields in non-drought stressed soybean production systems in the Coastal Plain soils of the Mid-

Atlantic USA growing region, at yields up to 5000 kg ha^{-1}. Tissue analysis of N and B concentrations were within or above published sufficiency ranges for optimum soybean yields (Mills and Jones, 1996; Gupta, 1993). Overall, the N and B fertilization of nodulating soybean appears to have no significant effect on yield levels.

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Table 1— Selected chemical properties for soils utilized in the cultivar and row spacing effect experiment in 1997-1999

Year	Depth	CEC†	pH	OM‡	N§	P¶	K#	Mg#	Ca#	B††	Mn‡‡	Zn§§
	cm	cmol kg^{-1}		%	---------------------------mg kg^{-1}---------------------------							
1997	0-15	na¶¶	6.5	2.0	na	13	100	55	510	0.3	2	1
1998	0-15	2.7	6.1	1.0	33	51	57	67	400	0.1	7	3
	15-31	2.1	5.9	0.5	20	46	47	33	337	0.1	11	4
	31-61	4.0	5.2	0.9	15	11	114	49	410	0.1	4	1
	61-94	4.4	4.7	0.3	14	7	72	48	274	0.1	1	1
1999	0-15	3.9	6.4	1.2	13	92	184	126	480	0.2	94	17
	15-31	5.5	6.5	1.4	9	75	149	132	557	0.1	87	11
	31-61	4.1	6.9	0.8	8	17	119	132	424	0.1	47	2
	61-94	5.0	7.0	0.6	9	5	116	177	512	0.1	18	1

†--CEC, cation exchange capacity, as determined by summation of cations

‡--OM, organic matter, as determined by the Walkley-Black method in all years

§--N, nitrogen, comprised of $NH_4^+ + NO_3^-$

¶--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined by Bray P1 extraction

#--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined by 1NAoAc extraction

††--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 determined as hot water soluble

‡‡--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 by Mehlich III extraction

§§--In 1997 determined by Mehlich I extractant, and in 1998 and 1999 by 0.1N HCl

¶¶--na, not available

Table 2—Nutrient content of the uppermost fully expanded leaves at R1 stage for cultivar and row spacing effect experiment, 1997-1999, prior to treatment applications.

Year	Cultivar	N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al
		------------------------------g kg^{-1}------------------------------												
1997	**Graham**	**na†**	**3.2**	**2.6**	**26.3**	**3.4**	**9.0**	**0.1**	**0.051**	**0.035**	**0.026**	**0.137**	**0.015**	**0.077**
	Hutcheson	**na**	**2.8**	**3.2**	**28.3**	**3.3**	**6.9**	**0.1**	**0.059**	**0.029**	**0.023**	**0.103**	**0.012**	**0.063**
1998‡	**TS 415**	**52.5**	**4.1**	**7.0**	**24.4**	**6.1**	**10.3**	**0.1**	**0.051**	**0.069**	**0.057**	**0.171**	**0.018**	**0.077**
	DP 3478	**51.3**	**3.4**	**6.8**	**22.6**	**5.4**	**9.0**	**0.2**	**0.043**	**0.067**	**0.046**	**0.146**	**0.028**	**0.058**
1999	**TS 415**	**55.5**	**3.6**	**4.2**	**21.9**	**4.1**	**10.1**	**0.3**	**0.052**	**0.063**	**0.12**	**0.147**	**0.009**	**0.048**
	DP 3478	**50.9**	**3.1**	**3.7**	**24.2**	**4.8**	**10.8**	**0.4**	**0.065**	**0.059**	**0.113**	**0.138**	**0.006**	**0.056**
	Holladay	**52.0**	**3.3**	**3.6**	**24.3**	**4.6**	**9.9**	**0.3**	**0.059**	**0.057**	**0.09**	**0.093**	**0.006**	**0.109**

†--na, not available

‡--Results for Holladay in 1998 not reported, sample not taken.

Table 3— Selected chemical properties† for soils utilized in the planting date and irrigation level experiment, 1998-1999.

Year	Depth	pH	P	K	Mg	Ca	B	Mn	Zn
	---cm---		---------------------------			mg kg^{-1}		---------------------------	
1998	0-20	6.5	42	116	44	557	na‡	3.2	4.5
1999	0-20	6.6	55	44	54	371	na	2.8	1.9

†--As determined by Mehlich I extraction

‡--Not available

Table 4—Nutrient content of the uppermost fully expanded leaves at R1 stage for planting date and irrigation level experiment, 1998-1999, prior to treatment applications.

Year	Planting date	N	S	P	K	Mg	Ca	Na	B	Zn	Mn	Fe	Cu	Al
		--g kg^{-1}---												
1998†	First	57.3	3.5	6.2	30.0	4.9	11.9	0.5	0.058	0.06	0.04	0.201	0.012	0.038
1999	First	61.2	3.3	6.0	22.0	5.0	11.9	0.1	0.032	0.047	0.07	0.181	0.008	0.033
1999	Second	60.4	3.5	7.2	30.3	6.2	9.8	0.1	0.035	0.062	0.077	0.171	0.009	0.037

†--Sample not taken for second planting date in 1998

Table 5. Average Watermark sensor readings correlated to soil moisture (Irrometer Co., 1999).

Meter Reading	Description of Soil Moisture State
0-0.1	Soil profile saturated
0.1-0.3	Adequate Moisture
0.3-0.6	Irrigate on most soils
0.6-1.0	Irrigate on clay soils
1.0-2.0	Soil is very dry, production may be water limited

Figure 1--Daily soybean water use at various development stages. Reproduced from Van Doren and Reicosky, 1987, p. 406.

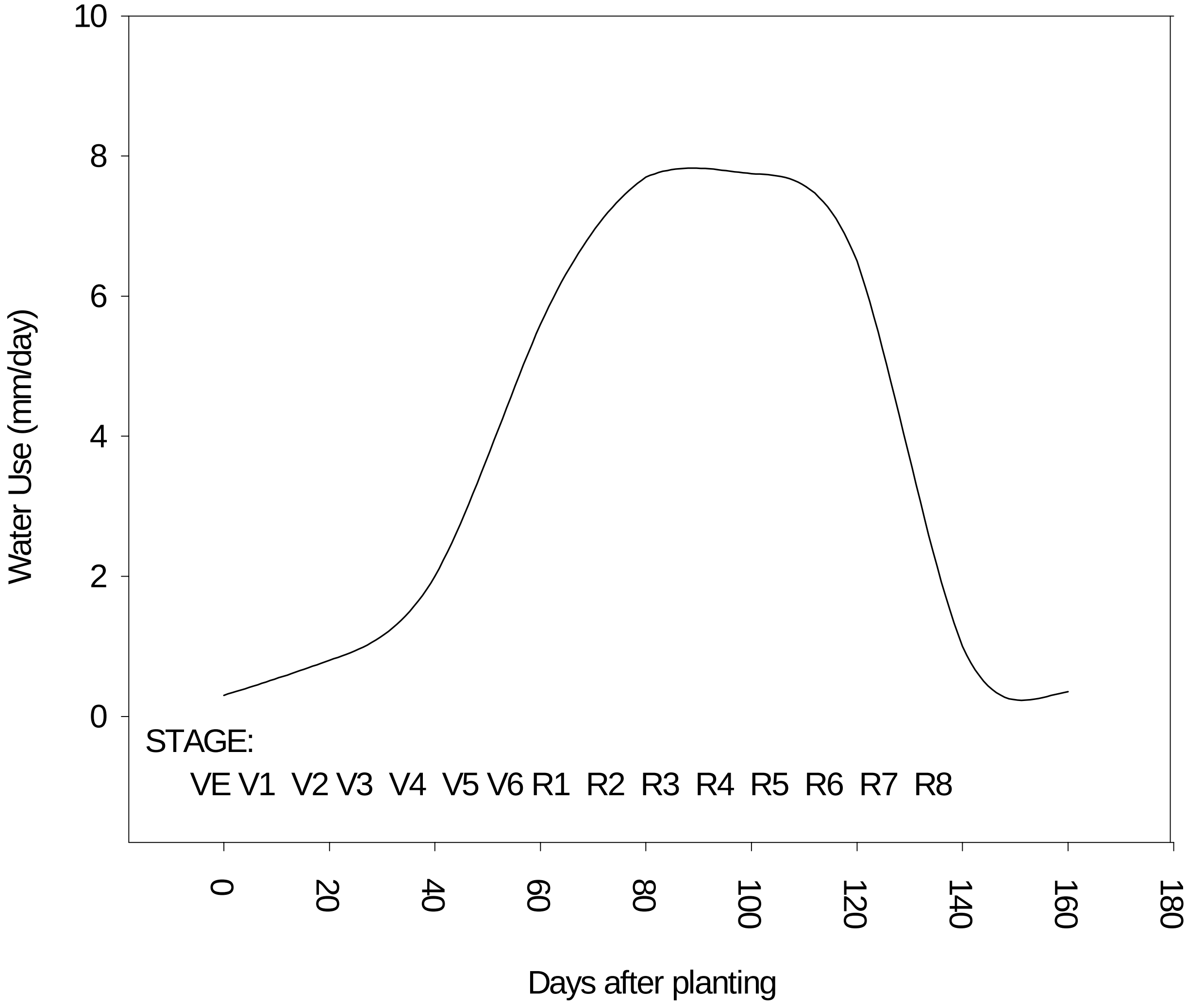


Figure 2—Soil moisture at 31, 61, and 91 cm and average daily rainfall in 1998, May planting date.

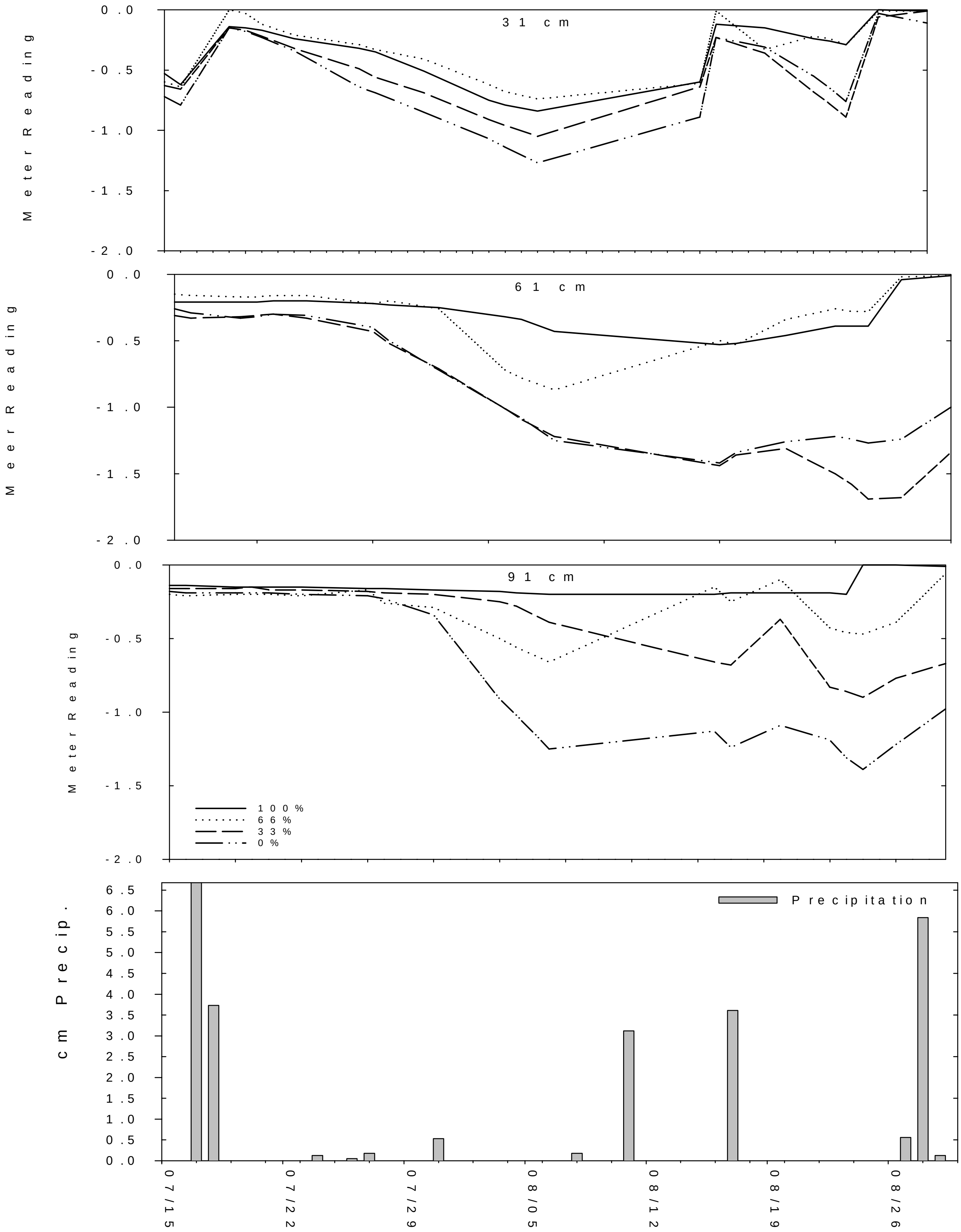


Figure 3—Soil moisture at 31, 61, and 91 cm and average daily rainfall in 1998, June planting date.

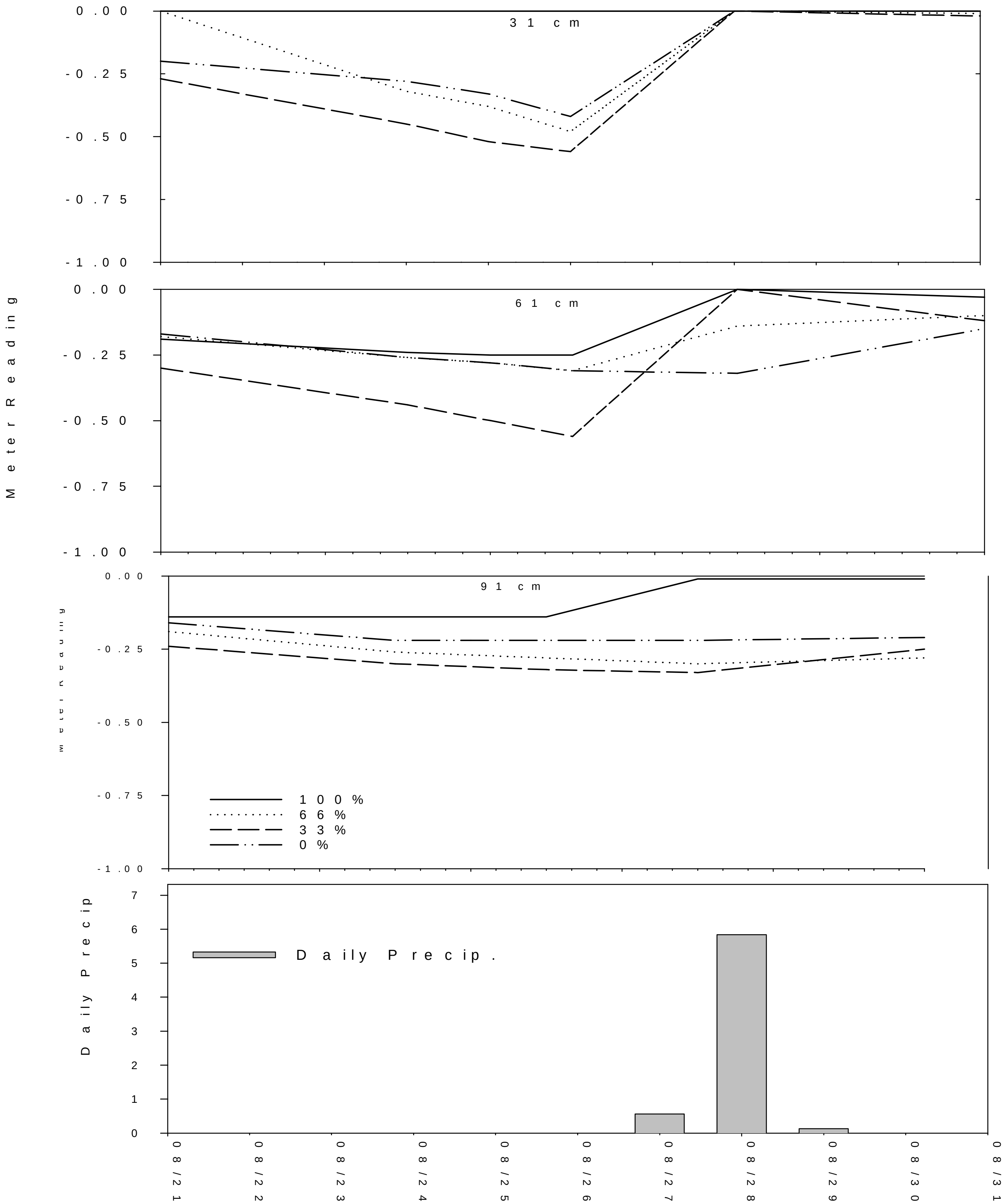


Figure 4—Average Daily and Cumulative Precipitation for 1998

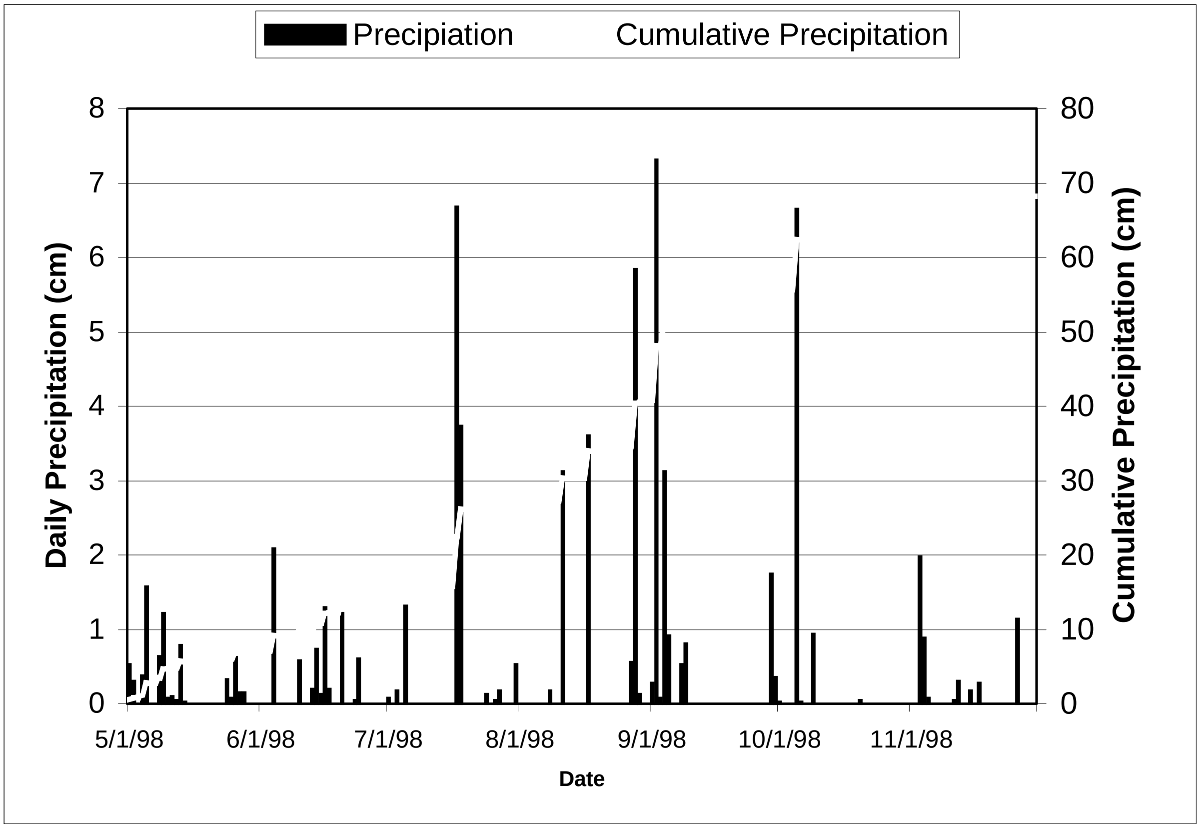


Figure 5—Average Daily and Cumulative Precipitation for 1999.

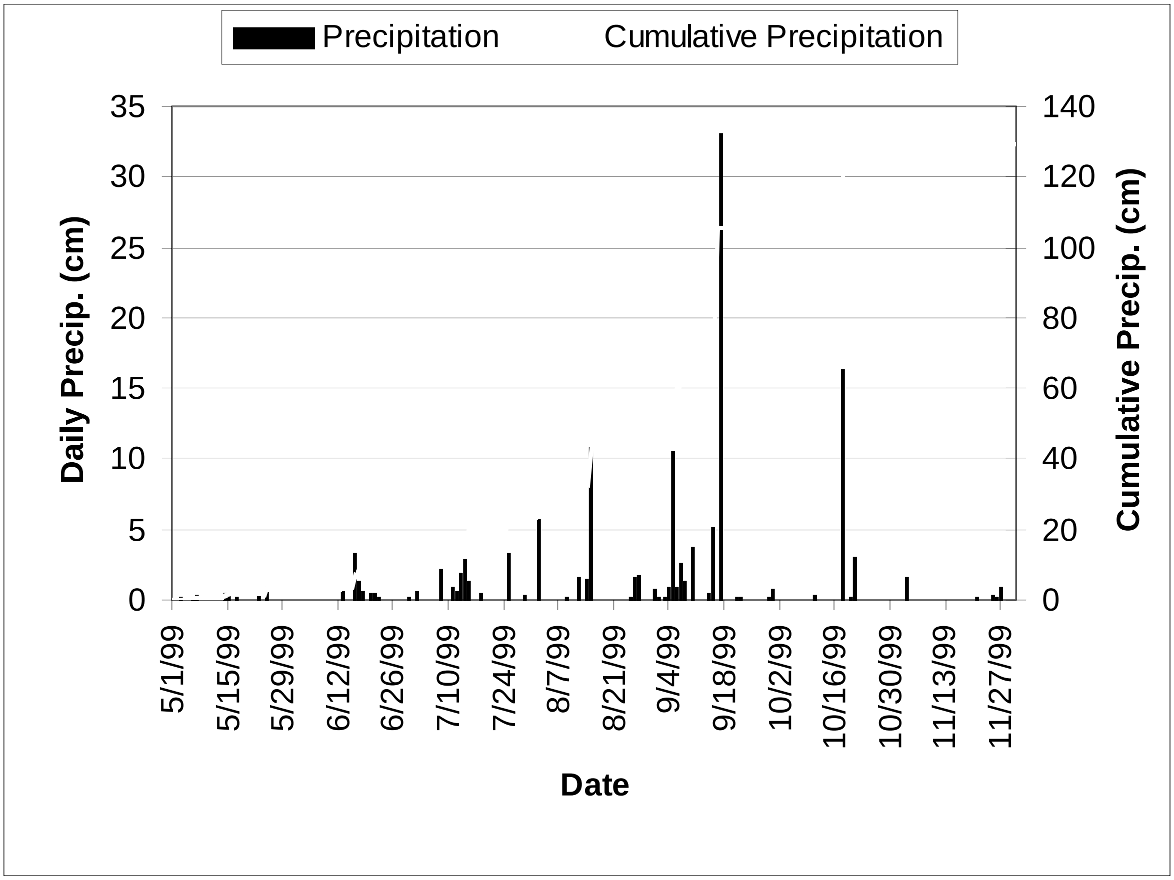
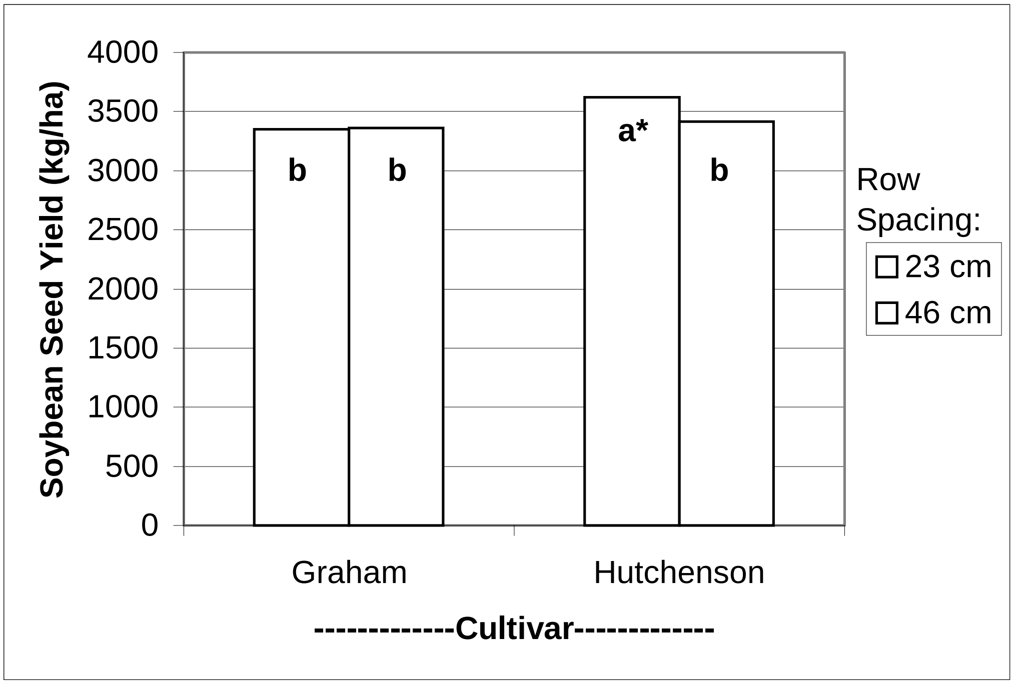
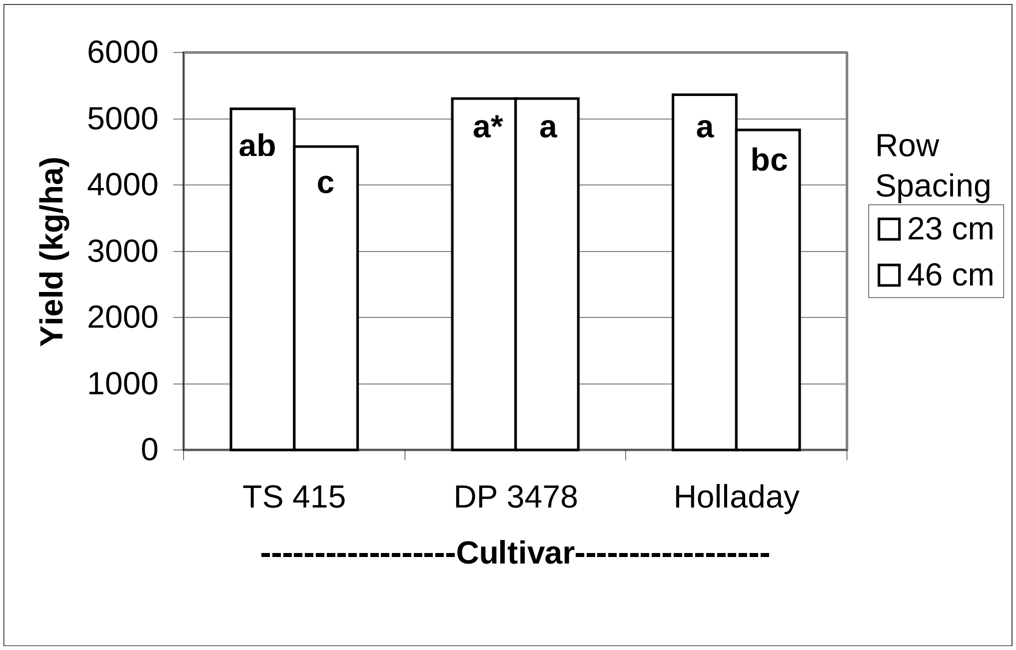


Figure 6—Average soybean seed yield (kg ha^{-1}) for cultivar and row spacing effects experiment, by cultivar and row spacing in 1997.



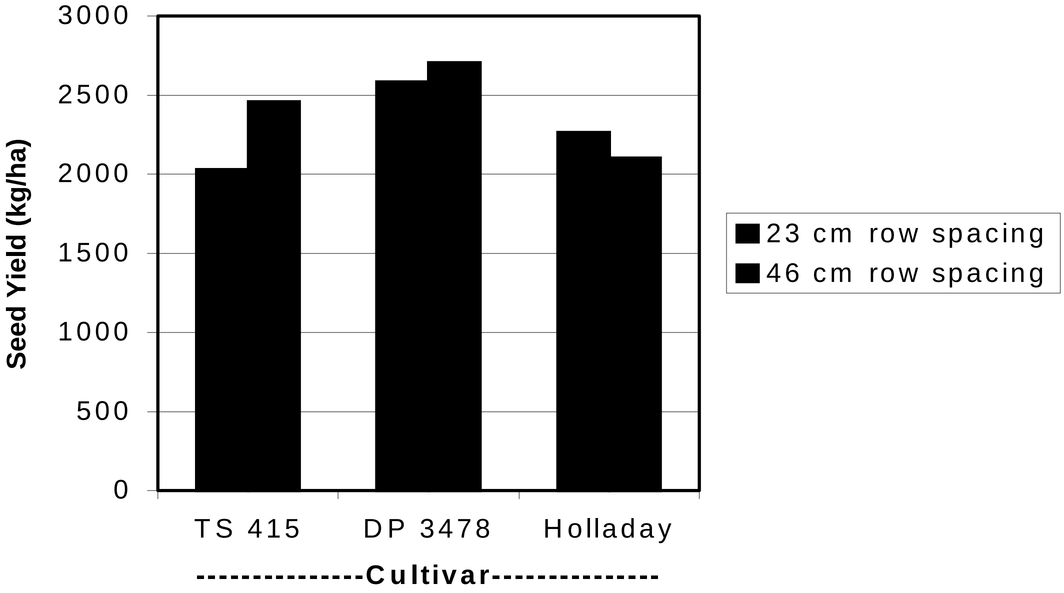
*--Means marked with the same letter are not significantly different using Tukey's HSD at the p=0.1 level.

Figure 7—Average soybean seed yield (kg ha^{-1}) for cultivar and row spacing effects experiment, by cultivar and row spacing in 1998.



*--Means marked with the same letter are not significantly different using Tukey's HSD at the p=0.1 level.

Figure 8—Average soybean seed yield (kg ha^{-1}) for cultivar and row spacing effects experiment, by cultivar in 1999.



*--Means marked with the same letter are not significantly different using Tukey's HSD at the p=0.1 level.

SUMMARY

Past work investigating effects of nitrogen (N) and boron (B) on soybean seed yield have been inconsistent. Over the past three years, our irrigated rate and timing experiments have investigated four rates of foliar B applications (0, 0.14, 0.28, or 0.56 kg ha^{-1}) applied at two soybean development stages (R3 and R5), and seven N rates (0, 28, 56, 84, 112, and 168 kg ha^{-1}), applied as UAN to the soil, at two soybean development stages (R3 and R5). In addition, our cultivar and row spacing experiment examined the yield effect of four combinations of N and B comprised of either 0 N and 0 B; 56 kg ha $^{-1}$ N, and 0 B; 0 N and 0.28 kg ha^{-1} B; and finally 56 kg ha^{-1} N and 0.28 kg ha^{-1} B applied to three soybean cultivars planted in either 23 or 46 cm row spacing. A final soil moisture and planting date experiment investigated the yield effects of the same N and B combinations on yield of soybeans planted either in May or June and irrigated at four levels via a sub-surface micro dip irrigation system. Unfortunately, due to the lack of a rainfall exclusion shelter, the irrigation regimes only existed for one year. Applications of N and B had no significant effects on soybean seed yield, regardless of rate, timing, cultivar, row spacing, planting date, or irrigation level. These results indicate that native soil B levels and N from symbiotic fixation and mineralization are adequate for high yields (>5000 kg ha^{-1}) in the coastal plain production region of the Mid-Atlantic area.

Vita

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John R. Freeborn was born in Tazewell, Virginia on August 17, 1976. He is the son of Dennis and Ingrid Freeborn of Rocky Gap, Virginia. John graduated from Virginia Polytechnic Institute and State University (Blacksburg, VA) summa cum laude in May of 1998 and married his wife, Randa, in June of 1998. He received a B.S. in Crop and Soil Environmental Science. John worked with Dr. David Holshouser and Dr. Norris Powell in Suffolk during the summers of 1998 and 1999. While on campus through the regular semester, he continued to work with Dr. Marcus Alley.