Final Report to Delaware Soybean Board
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Delaware Soybean Board (danielle.rrconsulting@gmail.com)

Irrigated Full Season Soybean Response to Nitrogen, Sulfur, and Complete Fertility Programs

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OBJECTIVES

1) Evaluate the effects of nitrogen and sulfur applied through a center pivot irrigation on full season soybean growth and yield.
2) Determine the optimal timing for nitrogen and sulfur applications for maximum yield.
3) Evaluate the effect of nitrogen applied without sulfur on soybean yield.
4) Determine if nutrients other than nitrogen and sulfur are limiting yield.
5) Evaluate the effect of high fertility levels on yield and tissue nutrient analysis.
6) Observe leaf tissue fertility levels with granular vs foliar applications.

FIVE YEAR AVERAGE YIELD SUMMARY

In research conducted at the University of Delaware Warrington Irrigation Research Farm in 2015, 2016, 2017, 2018, and 2019 a significant yield increase with N + S applications compared to the control have been observed in 4 out of 5 years. In 2015 and 2016, there was an 8 bu/A increase in yield when N + S (30 lbs/A + 15 lbs/A) was applied at the R1 growth stage compared to the no fertigation treatment. In 2017, the R1 application yielded similarly to the no fertigation treatment, however there was a 7 bu/A increase in yield over the no fertigation treatment when N + S was applied at R1 and again at R3 (60 lbs/A N + 30 lbs/A S total). In 2018, there was not a significant yield response with any rate or timing of N + S. In 2019, there was a 4 bu/A yield increase over the no fertigation treatment when N + S was applied at V3 + R1 (60 lbs/A N + 30 lbs/A S total), however this treatment was statistically similar to all other fertigation treatments except the treatments at V3 (30 lbs/A N) and at R1 (30 lbs/A N + 15 lbs/A S).

JUSTIFICATION

Soybean yields have been gradually increasing over the last 30 years due to genetic and management improvements. Traditionally, soybeans have been grown without nitrogen (N) fertilization due to the inherent ability to fix N in nodules and to obtain sufficient residual and mineralized N from the soil to meet crop needs. However, in a high yield scenario, particularly under irrigation where water is not a limiting factor, soybeans may not have the ability to fix enough N or obtain enough N from the soil to maximize yields. In addition, some of the sandy and low organic matter soils found in Delaware may not be able to supply sufficient sulfur (S) in a high yield scenario.

There has been a limited amount of research conducted locally on applying supplemental N to irrigated full season and double cropped soybeans. Results from other areas of the country that have applied N to soybean have been inconsistent and have shown both negative and positive yield responses. In addition,

there is limited research available on evaluating the response of irrigated soybean to S. Growers on Delmarva have reported positive yield responses to N + S fertigation through a center pivot irrigation when applied at flowering (R1/R2) or beginning pod (R3) or beginning seed fill (R5) growth stages.

Many soybean producers are using tissue testing as an in-season tool to determine and adjust fertility levels. However, very little information exists on the efficacy of this tool for other than crop nutrient deficiency troubleshooting. In addition, little information is available on how in-season fertilizer applications affect tissue nutrient levels and whether this tissue level change corresponds to an increase in yield.

REVIEW

In a high yield scenario, particularly under irrigation where water is not a limiting factor, soybeans may not have the ability to fix enough N or obtain enough N from the soil to maximize yields. On average, 50-80% of soybean N demand is met by N fixation across a wide range of yield levels and environments (Salvagiotti et al. 2008). The remaining N demand must come from the soil or fertilizer N, particularly as soybean yields increase above 65 bu/A.

In situations where soil nitrate concentration is high, there could potentially be a negative effect on the N fixation process in the nodules and put a constraint on N uptake (Streeter, 1988). In these situations, it is possible that the crop substitutes the normal N fixation with the additional N supply in the soil or that more N is translocated from vegetative reserves as the rate of N fixation is lowered (Herridge et al. 1984). Hungria et al. (2005) found that early season N applications often resulted in temporary suppression of nodule establishment and activity.

Maximum N fixation occurs between the R3 and R5 stages of soybean development (Zapata et al., 1987), and it may be necessary to provide fertilizer N during these stages if crop N demand is not met by N fixation or soil N supply. In a review of published research on N fertilization of soybeans by Salvagiotti et al. (2008), greater than half of the studies produced a positive yield response to applied N fertilizer. In these studies, yields were increased on average of 8 bu/A and the magnitude of response did not significantly differ among N rate categories of 0-45 lbs/A, 45-90 lbs/A, and >90 lbs/A. However, the largest maximum agronomic N use efficiency was observed when <45 lbs N/A was applied after R3 and was almost 3 times higher than the N use efficiency of <45 lbs N/A applied before R3.

Delaware Results

In 2015, 2016, 2017, 2018, and 2019 the Delaware Soybean Board funded trials to evaluate nitrogen and sulfur fertigation on irrigated full season soybeans.

- In 2015 and 2016, nitrogen (N) + sulfur (S) was applied at R1, R3, R5, R3 + R5, and R1 + R3 + R5 at 30lbs N + 15 lbs S per acre at each timing. Soybeans received a total of 30 lbs N + 15 lbs S per acre in the R1, R3, and R5 treatments, whereas the R3 + R5 treatment received a total of 60 lbs N + 30 lbs S per acre and the R1 + R3 + R5 treatment received a total of 90 lbs N + 45 lbs S per acre.
- In 2017, the number of treatments were reduced due to severe deer damage early in the season. Treatments included N + S applications at R1 (30 lbs N + 15 lbs S), R1 + R3 (60 lbs N + 30 lbs S total), and R1 + R3 + R5 (90 lbs N + 45 lbs S total).
- In 2018, N + S and UAN (without S) were applied at multiple timings and rates. The application timings were selected based on previous Delaware research results. Applications were made at

R1 and at R1 + R3. Total N and S applied ranged from 7.5 lb N/A + 3.5 lb S/A to 90 lb N/A + 45 lb S/A. A high fertility treatment was also included for comparison in an attempt to eliminate fertility as a yield limiting factor. The high fertility treatment consisted of a broadcast granular application of a complete fertilizer and a foliar application of Molybdenum at R1.

- In 2019, N + S and UAN (without S) were applied at multiple timings and rates. Applications were made at V3, R1, V3 + R1, R1 + R3, and V3+R1+R3. Total N and S applied ranged from 30 lb N/A + 0 lb S/A to 90 lb N/A + 45 lb S/A. A high fertility treatment was also included, which consisted of a broadcast granular application of a complete fertilizer and a foliar application of Molybdenum at V3.

In 2015 and 2016, the largest yield response was from the R1 treatment where soybeans yielded 8 bu/A greater than the no fertigation treatment. Yield was not improved and was slightly less than the R1 treatment when single applications were delayed to R3 and R5 and when multiple applications (R3 + R5 and R1 + R3 + R5) were made. The most noticeable increase in tissue N concentration over the no fertigation treatment was when N was applied at R1; however, all treatments had similar tissue N concentration in the final tissue analysis after the R5 treatment was applied.

In 2017, the R1 treatment yielded similar to the no fertigation treatment. However, there was a significant increase in yield (8 bu/A) when N + S was applied at R1 followed by another application at R3 for a total of 60 lbs N + 30 lbs S. This was the first year that evaluated the R1 + R3 application. Yield was not improved by applications at R1 + R3 + R5 (90 lbs N + 45 lbs S) over the R1 + R3 application. There was a noticeable increase in tissue N after all application timings compared to the control. With S tissue levels, the most noticeable increase occurred after the R3 application was made compared to the control. In the final tissue analysis, N and S levels remained highest in the multiple application treatments.

In 2018, all treatments yielded similar to the no fertigation treatment. The treatments that included only N (UAN) were the lowest yielding. Although there were no yield differences across treatments, tissue analysis revealed increases in N and S due to the N and S applications. With the high fertility treatment, no significant increase in tissue levels were observed with P and Ca, however, K and Mg tissue levels were higher than nontreated plots 1 week after application, but not at other tissue sampling timings. All micronutrient (B, Mn, Zn, and Mo) tissue levels in the high fertilility treatment were higher than nontreated treatments at all tissue sampling timings after application. It is very interesting that the increase in K, Mg, and micronutrient tissue levels did not improve yield. There were no significant differences in plant height compared to the nontreated control.

2019 Results

Yields

The high fertility (granular) plots had the greatest absolute yield (Table 3), but was still similar to other treatments, including the high fertility foliar plots. Many of the treatments were similar to each other, but the high fertility (granular) yield was significantly higher than no fertigation, V3(N), R1/R3(N+S), and the R1(N+S) yields. The variability and overlap in treatment effects could point to the multiple factors affecting yield, including soil type and past applications in these plots. There is potential that variable mineralization rates across plots also convoluted the results, masking the effects of additional N and S to soybeans.

What is certain is that V3+R1 additions that included N and S had a 7 bu/A increase in yield over the absolute lowest treatment effect (R1[N+S]). The inclusion of R3 without high fertility did not push yields quite as high, even though it was similar to other treatments. In 2019, it appears that R3 N may not have been as much value as earlier N+S applications.

Tissue Levels

For tissue N, all samples were above critical thresholds and there were also some significant differences at the R1 growth stage. Tissue N at R1 was at the absolute highest value at V3/R1/R3 (N+S) and V3/R1/R3 (N+S) high fertility granular, similar to some of the yield effects seen. However, at the R1 sampling, the R3 N+S had not been added yet so there appears to be some kind of plot level effect. Statistically, the treatments that would have had N added at R3 were similar to the V3/R1 treatments, which makes sense as they had similar amounts of N+S applied. The high fertility (granular) treatment was absolutely higher in tissue N than no fertigation, V3(N), R1(N), and R1(N+S), so those earlier treatments by themselves do not push more N into the plant tissue.

Tissue S only had differences at R1 and R3 sampling times, which appears to be related to N+S applications at V3 and R1. No samples were lacking in S, even without additional fertigation.

Phosphorus was also above critical values across all samples (Table 4) and was not really improved through the high fertility treatments. There was also no observable effect on tissue P due to N+S additions at any stage. Potassium, while still within critical K thresholds from V3 to R3, had some differences in tissue levels at R3. For the most part, it appears that fertigation with N+S suppresses K in the leaf tissue at R3, particularly with greater N+S applied at the later stages. However, many treatments had similar K effects with N+S additions.

Magnesium and Ca were also within suggested critical levels at all stages and had some treatment effects due to N+S additions. The results are not clear as to the meaning, as one of the lowest Mg concentrations was at both no fertigation and high fertility foliar, while Ca was highest at the R3 stage with no fertigation. The relationship of Ca and Mg to N or S additions would warrant specific studies tailored to those additions, as these results appear scattershot. It is possible that S could have assisted with Mg uptake, but the same results are not seen with Ca.

Micronutrients paint the clearest picture from the 2019 data, with high fertility granular applications increasing levels of B, Mn, Mo, and Zn. Only Cu and Fe were not increased by high fertility. For Cu and Fe, soil levels are either adequate, or increasing uptake of either nutrient is difficult under these conditions. Our soils appear to have adequate levels of both Fe and Cu across the region, and pH may be a larger driver of issues with Cu or Fe in grain crops.

For B, it may be possible that later (R3) applications of N+S increase uptake, but often no fertigation was the second highest B level. It may also be possible that mid-season N+S applications suppress B uptake, but this is made up for when B is added in the high fertility granular plots. While Mn and Mo were only increased by the high fertility (granular) plots at R3, the N+S treatments did have some affect on Mo at the R1 sampling stage. The results are not clear however, and the high fertility (granular) plots drive more of the Mo uptake in this study. For Zn, R1 applications of N or N+S may increase uptake, although only at 30lbs N/acre, as it appears that 60lbs N may suppress Zn uptake.

Over all years, a significant yield increase with N + S applications compared to the control have been observed in 4 out of 5 years. However, there is not a consistent application timing that gives the significant increase. Data indicates that early reproductive stage application timings provide the highest possibility for a yield increase at the yield levels obtained in these studies.

MATERIALS AND METHODS

A study was conducted in 2019 to determine the response of full season soybeans to nitrogen plus sulfur fertigation under center pivot irrigation. All the work was conducted under a variable rate four tower center pivot irrigation system located on the University of Delaware's Warrington Irrigation Research Farm in Harbeson, DE.

Treatments. Plots measured 90 ft by 90 ft. Each plot received one of the following treatments. All treatments were replicated five times.

1. Untreated
2. V3 Fertigation - 30 lbs N (UAN, no sulfur)
3. R1 Fertigation - 30 lbs N (UAN, no sulfur)
4. V3 + R1 Fertigation - 30 lbs N (UAN, no sulfur) at each timing (60 lbs N total)
5. R1 + R3 Fertigation - 30 lbs N (UAN, no sulfur) at each timing (60 lbs N total)
6. V3 Fertigation - 30 lbs N + 15 lbs S
7. R1 Fertigation - 30 lbs N + 15 lbs S
8. V3 + R1 Fertigation - 30 lbs N + 15 lbs S at each timing (60 lbs N + 30 lbs S total)
9. R1 + R3 Fertigation - 30 lbs N + 15 lbs S at each timing (60 lbs N + 30 lbs S total)
10. V3 + R1 + R3 Fertigation – 30 lbs N + 15 lbs S at each timing (90 lbs N + 45 lbs S total)
11. High fertility (complete fertilizer granular) V3 application + V3 + R1 + R3 Fertigation – 30 lbs N + 15 lbs S at each timing (90 lbs N + 45 lbs S total)
12. High fertility (complete fertilizer foliar) V3 + R1 application + V3 + R1 + R3 Fertigation – 30 lbs N + 15 lbs S at each timing (90 lbs N + 45 lbs S total)

High Fertility Plots. Dry fertilizer was broadcast with a Chabin push spreader at growth stage V3. Nutrients and rates applied included phosphorus at 75 lbs/A, potassium at 150 lbs/A, magnesium at 35 lbs/A, calcium at 50 lbs/A, sulfur at 98 lbs/A, manganese at 1 lb/A, boron at 1 lb/A, and zinc at 1 lb/A. Molybdenum was applied foliarly at 0.043 lbs/A (Moly-16; 11.4 lbs/gal; 3 oz/A).

Micronutrient Foliar. A commercially available foliar fertilizer product (Task Force 2; Loveland Products, Inc.) was applied 4 times at a 2 qt/A rate. Applications began at V3 and were applied on 7 day intervals to R1. Each application consisted of nitrogen (0.56 lbs/A), phosphorus (0.41 lbs/A), potassium (0.25 lbs/A), boron (0.001 lbs/A), cobalt (0.000026 lbs/A), copper (0.0026 lbs/A), iron (0.005 lbs/A), manganese (0.0026 lbs/A), molybdenum (0.000026 lbs/A), and zinc (0.0026 lbs/A).

Field Operations. Fertilizer was applied based on the University of Delaware recommendations for soybeans. Soybeans were planted into conventionally tilled soil with a Monosem planter in 15 inch rows. Irrigation was applied under limited irrigation (>30% soil moisture) until flowering (R1) then soil moisture was maintained at >50% until maturity. Planting date, soybean variety, seeding rate, pesticide applications, and harvest date are presented in Table 1.

Table 1. Planting date, variety, seeding rate, pesticide applications, and harvest date.

Operation	**Full Season Study**
Planting Date	5/2/19
Variety	Credenz CZ4308LL
Target Seeding Rate/A	150,000
Pesticide Applications	
Canopy 4 oz/A	5/2/19
Liberty 22 oz/A + Dual 1.0 pt/A	6/15/19
Trivapro 13.7 oz/A + Hero 10.3 oz/A	7/24/19
Harvest Date	11/6/19

Soil Moisture Monitoring to Trigger Irrigation Treatments. Soil moisture was monitored using Watermark soil moisture sensors placed at 4 in., 10 in., and 16 in. below the soil line. Soil moisture data was transmitted wirelessly approximately 10 times daily from the field to a data logging receiver. Moisture data was viewed and interpreted daily to determine if irrigation was required. Irrigation was triggered whenever soil moisture reached the specific threshold at the 4 in. or 10 in. depth. Weather data was collected by a Delaware Environmental Observing System weather station located on the irrigation research farm.

Data Collected. Plant growth and development data was collected throughout the season at various growth stages. Soybean growth stages (Table 2), and plant heights were recorded on multiple dates. Soil samples were taken 6 inches deep from each plot before fertigation treatments began to determine baseline soil nitrogen levels. Tissue samples were collected before the first fertigation treatment (V3) and 1 week after each fertigation treatment timing (V3, R1, R3) to determine leaf nutrient content. Plots were harvested with a Massey Ferguson 8XP plot combine. Soybean yield was adjusted to 13% moisture.

Data Analysis. Data was analyzed using JMP and treatments means compared using Fisher's Least Significant Difference (LSD) test at the 5% probability level. The data collected was analyzed to determine the effects of nitrogen and sulfur fertigation on plant growth, development, and yield.

Table 2. Soybean growth stages by date.

Growth Stage	Growth Stage Description	Date
V2	2-trifoliolate	6/1/19
V4	4-trifoliolate	6/15/19
V6	6-trifoliolate	6/21/19
R1	Begin Flower	6/27/19
R2	Full Flower	7/1/19
R3	Begin Pod	7/15/19
R4	Full Pod	7/26/19
R5	Begin Seed	8/7/19
R6	Full Seed	8/24/19
R7	Begin Maturity	9/15/19
R8	Full Maturity	10/1/19

Table 3. **Full Season Study 2019** – Fertigation treatment effect on soybean yield and nitrogen and sulfur tissue content.

Fertigation Treatment	Total N + S	Yield	Tissue[1]							
			Nitrogen				Sulfur			
		2019	V3	R1	R3	R5	V3	R1	R3	R5
	lbs/A	bu/A	%				%			
No fertigation	0 + 0	68.1 cde[2]	4.76 a	4.82 cd	5.72 a	6.59 ab	0.28 a	0.26 c	0.29 def	0.34 a
V3	30 + 0	67.7 de	4.33 b	4.83 cd	5.95 a	6.26 bc	0.26 ab	0.28 b	0.28 f	0.31 a
R1	30 + 0	71.1 abcd	4.38 b	4.85 cd	5.68 a	6.09 c	0.26 b	0.25 c	0.29 cdef	0.32 a
V3 + R1	60 + 0	70.1 abcd	4.50 ab	5.01 abcd	5.40 a	6.49 abc	0.28 ab	0.28 b	0.31 abcd	0.34 a
R1 + R3	60 + 0	69.1 bcde	4.31 b	5.10 abc	5.89 a	6.40 abc	0.26 b	0.25 c	0.28 ef	0.33 a
V3	30 + 15	69.8 abcde	4.34 b	5.05 abcd	5.71 a	6.60 ab	0.26 ab	0.28 b	0.29 def	0.33 a
R1	30 + 15	65.8 e	4.40 ab	4.75 d	5.51 a	6.56 ab	0.26 b	0.25 c	0.31 abcd	0.33 a
V3 + R1	60 + 30	72.7 ab	4.38 b	5.22 ab	5.66 a	6.56 ab	0.27 ab	0.30 ab	0.33 a	0.33 a
R1 + R3	60 + 30	71.8 abc	4.37 b	4.88 bcd	5.59 a	6.76 a	0.26 ab	0.26 c	0.30 bcde	0.31 a
V3 + R1 + R3	90 + 45	70.5 abcd	4.50 ab	5.28 a	5.71 a	6.41 abc	0.27 ab	0.30 a	0.31 abc	0.32 a
V3 + R1 + R3 + High fert. (Granular)	90 + 45	73.3 a	4.39 b	5.35 a	5.75 a	6.36 abc	0.26 b	0.31 a	0.32 ab	0.34 a
V3 + R1 + R3 + High fert. (Foliar)	90 + 45	72.7 ab	4.40 b	5.22 ab	5.47 a	6.40 abc	0.26 ab	0.30 ab	0.33 ab	0.33 a
			NS		NS	NS	NS			NS
Sufficiency Range[3]			4.26 - 5.50				0.18 – 0.30			

[1]Tissue samples were collected 2 weeks after each fertigation timing.

[2]Treatment means followed by the same letter are not significantly different. NS=not significant.

[3]Sufficiency range = Expected normal or sufficient range in nutrient concentration.

Table 4. **Full Season Study 2019** – Fertigation treatment effect on soybean phosphorus and potassium tissue content.

Fertigation Treatment	Total N + S	Tissue[1]							
		Phosphorus				Potassium			
		V3	R1	R3	R5	V3	R1	R3	R5
	lbs/A	%				%			
No fertigation	0 + 0	0.36 a[2]	0.40 a	0.51 ab	0.43 ab	2.78 ab	2.53 bc	2.36 a	1.97 a
V3	30 + 0	0.33 ab	0.40 a	0.52 ab	0.42 ab	2.74 abc	2.58 abc	2.20 abcd	1.83 ab
R1	30 + 0	0.34 ab	0.38 a	0.50 ab	0.41 ab	2.61 c	2.49 c	2.17 bcd	1.84 ab
V3 + R1	60 + 0	0.34 ab	0.41 a	0.50 ab	0.41 ab	2.81 a	2.60 abc	2.28 abc	1.89 ab
R1 + R3	60 + 0	0.32 ab	0.38 a	0.50 ab	0.44 a	2.70 abc	2.47 c	2.20 abc	1.99 a
V3	30 + 15	0.30 b	0.39 a	0.49 ab	0.40 ab	2.62 bc	2.60 abc	2.27 abc	1.88 ab
R1	30 + 15	0.35 a	0.38 a	0.47 b	0.40 ab	2.71 abc	2.44 c	2.13 cd	1.71 b
V3 + R1	60 + 30	0.31 ab	0.39 a	0.52 ab	0.41 ab	2.67 abc	2.56 bc	2.22 abcd	1.88 ab
R1 + R3	60 + 30	0.32 ab	0.39 a	0.46 b	0.39 b	2.68 abc	2.49 c	2.14 cd	1.82 ab
V3 + R1 + R3	90 + 45	0.34 ab	0.38 a	0.50 ab	0.42 ab	2.72 abc	2.58 abc	2.10 d	1.88 ab
V3 + R1 + R3 + High fert. (Granular)	90 + 45	0.34 ab	0.40 a	0.55 a	0.42 ab	2.64 bc	2.73 a	2.33 ab	2.01 a
V3 + R1 + R3 + High fert. (Foliar)	90 + 45	0.33 ab	0.40 a	0.47 b	0.43 ab	2.68 abc	2.67 ab	2.10 d	1.95 a
		NS	NS	NS	NS	NS	NS		NS
Sufficiency Range[3]		0.26 – 0.50				2.00 – 2.80			

[1]Tissue samples were collected 2 weeks after each fertigation timing.

[2]Treatment means followed by the same letter are not significantly different. NS=not significant.

[3]Sufficiency range = Expected normal or sufficient range in nutrient concentration.

Table 5. **Full Season Study 2019** – Fertigation treatment effect on soybean magnesium and calcium tissue content.

Fertigation Treatment	Total N + S	Tissue[1]							
		Magnesium				Calcium			
		V3	R1	R3	R5	V3	R1	R3	R5
	lbs/A	%				%			
No fertigation	0 + 0	0.45 ab[2]	0.38 e	0.37 c	0.33 b	1.00 a	0.78 a	0.86 a	0.91 ab
V3	30 + 0	0.45 ab	0.43 abc	0.41 ab	0.39 a	0.88 a	0.76 a	0.78 b	0.90 abc
R1	30 + 0	0.46 ab	0.45 a	0.43 a	0.39 a	0.90 a	0.76 a	0.80 ab	1.00 a
V3 + R1	60 + 0	0.45 ab	0.41 cde	0.39 bc	0.36 ab	0.98 a	0.76 a	0.80 b	0.89 abc
R1 + R3	60 + 0	0.44 ab	0.42 abcd	0.40 ab	0.39 a	1.07 a	0.76 a	0.78 bc	0.91 abc
V3	30 + 15	0.43 b	0.41 abcd	0.39 bc	0.36 ab	0.90 a	0.74 a	0.77 bc	0.80 bc
R1	30 + 15	0.46 ab	0.45 a	0.41 ab	0.39 a	0.97 a	0.75 a	0.78 b	0.92 ab
V3 + R1	60 + 30	0.45 ab	0.42 abcd	0.40 bc	0.34 ab	0.90 a	0.76 a	0.78 b	0.87 abc
R1 + R3	60 + 30	0.45 ab	0.42 abcd	0.39 bc	0.37 ab	0.91 a	0.80 a	0.80 ab	0.78 c
V3 + R1 + R3	90 + 45	0.47 a	0.44 ab	0.39 bc	0.38 ab	0.91 a	0.76 a	0.71 c	0.89 abc
V3 + R1 + R3 + High fert. (Granular)	90 + 45	0.44 ab	0.39 de	0.39 bc	0.35 ab	0.91 a	0.80 a	0.80 b	0.92 ab
V3 + R1 + R3 + High fert. (Foliar)	90 + 45	0.45 ab	0.41 bcde	0.37 c	0.37 ab	0.91 a	0.79 a	0.77 bc	0.88 abc
		NS			NS	NS	NS		NS
Sufficiency Range[3]		0.30 – 0.80				0.50 – 1.50			

[1]Tissue samples were collected 2 weeks after each fertigation timing.

[2]Treatment means followed by the same letter are not significantly different. NS=not significant.

[3]Sufficiency range = Expected normal or sufficient range in nutrient concentration.

Table 6. **Full Season Study 2019** – Fertigation treatment effect on soybean boron and manganese tissue content.

Fertigation Treatment	Total N + S	Tissue[1]							
		Boron				Manganese			
		V3	R1	R3	R5	V3	R1	R3	R5
	lbs/A	%				%			
No fertigation	0 + 0	27.6 ab[2]	27.4 b	30.6 b	33.0 bcd	77 a	65 b	72 b	76 b
V3	30 + 0	29.4 a	19.4 ef	22.2 cd	26.2 de	72 a	58 b	76 b	82 ab
R1	30 + 0	26.6 ab	22.6 cde	19.4 cd	25.6 de	73 a	67 b	72 b	82 ab
V3 + R1	60 + 0	28.4 ab	22.6 cde	25.2 bc	29.4 cd	71 a	59 b	69 b	93 ab
R1 + R3	60 + 0	27.4 ab	25.0 bc	23.2 cd	28.6 cde	71 a	66 b	68 b	78 b
V3	30 + 15	28.6 ab	20.0 def	23.0 cd	28.0 de	67 a	62 b	64 b	73 b
R1	30 + 15	26.2 ab	22.4 cde	18.4 d	21.2 e	75 a	71 ab	83 b	95 ab
V3 + R1	60 + 30	29.4 a	19.6 def	24.0 cd	28.2 de	69 a	57 b	71 b	79 ab
R1 + R3	60 + 30	26.8 ab	23.4 cd	21.6 cd	36.4 bc	69 a	61 b	68 b	78 b
V3 + R1 + R3	90 + 45	27.8 ab	18.4 f	19.6 cd	39.2 b	76 a	64 b	66 b	73 b
V3 + R1 + R3 + High fert. (Granular)	90 + 45	26.0 b	34.8 a	40.6 a	47.6 a	74 a	90 a	112 a	107 a
V3 + R1 + R3 + High fert. (Foliar)	90 + 45	28.6 ab	20.2 def	22.6 cd	39.6 ab	67 a	58 b	69 b	73 b
		NS				NS	NS		NS
Sufficiency Range[3]		21 – 60				25 – 200			

[1]Tissue samples were collected 2 weeks after each fertigation timing.

[2]Treatment means followed by the same letter are not significantly different. NS=not significant.

[3]Sufficiency range = Expected normal or sufficient range in nutrient concentration.

Table 7. **Full Season Study 2019** – Fertigation treatment effect on soybean molybdenum and copper tissue content.

Fertigation Treatment	Total N + S	Tissue[1]							
		Molybdenum				Copper			
		V3	R1	R3	R5	V3	R1	R3	R5
	lbs/A	%				%			
No fertigation	0 + 0	0.46 a[2]	0.34 c	0.12 b	0.32 a	12.9 ab	15.8 a	15.0 b	12.7 a
V3	30 + 0	0.38 a	0.37 c	0.17 b	0.18 c	9.6 ab	13.4 a	41.2 a	11.7 a
R1	30 + 0	0.50 a	0.54 bc	0.19 b	0.13 c	10.3 ab	13.8 a	18.6 b	22.8 a
V3 + R1	60 + 0	0.41 a	0.36 c	0.23 b	0.16 c	12.8 ab	14.4 a	15.6 b	12.3 a
R1 + R3	60 + 0	0.41 a	0.46 c	0.18 b	0.25 abc	11.3 ab	12.9 a	14.9 b	11.2 a
V3	30 + 15	0.35 a	0.52 bc	0.22 b	0.19 bc	13.1 ab	14.4 a	15.5 b	10.8 a
R1	30 + 15	0.53 a	0.70 b	0.26 b	0.23 ab	14.0 a	15.6 a	14.8 b	11.1 a
V3 + R1	60 + 30	0.35 a	0.47 bc	0.15 b	0.16 c	9.8 ab	15.2 a	18.0 b	10.8 a
R1 + R3	60 + 30	0.48 a	0.41 c	0.17 b	0.24 abc	9.6 b	14.2 a	14.6 b	10.8 a
V3 + R1 + R3	90 + 45	0.44 a	0.46 c	0.22 b	0.21 abc	10.5 ab	13.6 a	16.1 b	11.3 a
V3 + R1 + R3 + High fert. (Granular)	90 + 45	0.38 a	2.14 a	1.17 a	0.31 ab	11.2 ab	12.9 a	15.1 b	8.9 a
V3 + R1 + R3 + High fert. (Foliar)	90 + 45	0.38 a	0.43 c	0.18 b	0.19 c	11.1 ab	14.0 a	17.0 b	22.3 a
		NS			NS	NS	NS	NS	NS
Sufficiency Range[3]		0.21 – 4.00				6 – 20			

[1]Tissue samples were collected 2 weeks after each fertigation timing.

[2]Treatment means followed by the same letter are not significantly different. NS=not significant.

[3]Sufficiency range = Expected normal or sufficient range in nutrient concentration.

Table 8. **Full Season Study 2019** – Fertigation treatment effect on soybean iron and zinc tissue content.

Fertigation Treatment	Total N + S	Tissue[1]							
		Iron				Zinc			
		V3	R1	R3	R5	V3	R1	R3	R5
	lbs/A	%				%			
No fertigation	0 + 0	196 a[2]	96 b	95 ab	107 a	54 b	60 c	62 cd	64 b
V3	30 + 0	194 a	95 b	104 ab	109 a	58 ab	62 bc	67 bcd	71 ab
R1	30 + 0	188 a	195 a	129 a	106 a	71 a	76 ab	78 ab	91 a
V3 + R1	60 + 0	178 a	87 b	95 ab	99 a	55 b	61 c	62 cd	70 ab
R1 + R3	60 + 0	202 a	89 b	92 ab	139 a	57 ab	63 bc	63 cd	64 b
V3	30 + 15	209 a	98 b	93 ab	102 a	51 b	61 c	60 d	59 b
R1	30 + 15	193 a	99 b	89 b	99 a	64 ab	69 abc	84 a	72 ab
V3 + R1	60 + 30	163 a	90 b	107 ab	82 a	51 b	60 c	69 bcd	61 b
R1 + R3	60 + 30	206 a	91 b	94 ab	117 a	59 ab	65 abc	73 abcd	63 b
V3 + R1 + R3	90 + 45	185 a	94 b	89 b	137 a	54 b	62 bc	66 bcd	59 b
V3 + R1 + R3 + High fert. (Granular)	90 + 45	188 a	92 b	95 ab	90 a	62 ab	78 a	84 a	75 ab
V3 + R1 + R3 + High fert. (Foliar)	90 + 45	165 a	84 b	101 ab	94 a	55 b	64 abc	75 abc	64 b
		NS	NS	NS	NS	NS	NS		NS
Sufficiency Range[3]		50 – 350				20 – 50			

[1]Tissue samples were collected 2 weeks after each fertigation timing.

[2]Treatment means followed by the same letter are not significantly different. NS=not significant.

[3]Sufficiency range = Expected normal or sufficient range in nutrient concentration.

Table 9. **Full Season Study 2019** – Fertigation treatment effect on soybean height.

Fertigation Treatment	Total N + S	Height 6/14/19	7/12/19	11/6/19
	lbs/A	inches		
No fertigation	0 + 0	5.0 ab[1]	19.3 abcd	39.6 abc
V3	30 + 0	4.6 b	18.5 bcd	38.6 abcd
R1	30 + 0	4.9 ab	18.3 cd	36.1 cd
V3 + R1	60 + 0	4.7 ab	19.9 abc	40.6 ab
R1 + R3	60 + 0	4.6 b	18.5 bcd	37.9 bcd
V3	30 + 15	4.6 b	18.7 bcd	39.2 abc
R1	30 + 15	4.8 ab	17.6 d	35 d
V3 + R1	60 + 30	4.6 b	20.2 abc	40.5 ab
R1 + R3	60 + 30	4.7 ab	18.2 cd	37.8 bcd
V3 + R1 + R3	90 + 45	4.6 b	19.2 abcd	40.2 ab
V3 + R1 + R3 + High fert. (Granular)	90 + 45	4.9 ab	21.1 a	41.4 ab
V3 + R1 + R3 + High fert. (Foliar)	90 + 45	5.2 a	20.4 ab	41.7 a
		NS		

[1]Treatment means followed by the same letter are not significantly different. NS=not significant.