

**Final Report to Delaware Soybean Board
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Delaware Soybean Board (susanne@hammondmedia.com)

Evaluation of Nitrogen and Sulfur Fertigation Rates and Timings in Irrigated Full Season Soybeans

Cory Whaley, James Adkins, Jarrod Miller, and Phillip Sylvester

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 rates for nitrogen and sulfur applications for maximum yield.
- 3) Evaluate the effect of nitrogen applied without sulfur on soybean yield.
- 4) Evaluate the effect of high fertility levels on yield and tissue nutrient analysis.
- 5) Determine if nutrients other than nitrogen and sulfur are limiting yield.

FOUR YEAR AVERAGE YIELD TREND

In research conducted at the University of Delaware Warrington Irrigation Research Farm in 2015, 2016, 2017, and 2018 trends in soybean response to nitrogen (N) and sulfur (S) fertigation are developing. There was a significant yield response in three of four years when N + S was applied over the no fertigation treatment. 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.

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, and 2018 the Delaware Soybean Board funded trials to evaluate nitrogen and sulfur fertigation on irrigated full season and double crop 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 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 (Table 3). 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 (Tables 4 and 5). All micronutrient (B, Mn, Zn, and Mo) tissue levels in the high fertility treatment were higher than nontreated treatments at all tissue sampling timings after application (Tables 6, 7, and 8). 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 (Table 9).

Over all years, a significant yield increase with N + S applications compared to the control have been observed in 3 out of 4 years. Data indicates that early reproductive stage application timings provide the highest yield increase; however, applications before R1 during the vegetative stage have not been evaluated. In addition, it is necessary to again evaluate N applied without S. It is interesting to note that in all 4 years, average yield of all treatments combined was around 75 bu/A (data not shown). Although we did not see a yield response to the high fertility treatment in 2018, there was an influence on tissue nutrient levels observed. It would be interesting to gather more data on tissue levels between high fertility and University recommended fertility and their corresponding yields.

MATERIALS AND METHODS

A study was conducted in 2018 to determine the response of full season soybeans to nitrogen plus sulfur fertigation under center pivot irrigation. All of 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 four times.

1. No nitrogen or sulfur (control)
2. R1 Fertigation – 30 lbs N (UAN, no sulfur)
3. R1 + R3 Fertigation – 30 lbs N (UAN, no sulfur) at each timing (60 lbs N total)
4. R1 Fertigation – 15 lbs N + 7.5 lbs S
5. R1 Fertigation – 30 lbs N + 15 lbs S
6. R1 Fertigation – 60 lbs N + 30 lbs S
7. R1 Fertigation – 90 lbs N + 45 lbs S
8. R1 + R3 Fertigation – 7.5 lbs N + 3.75 lbs S at each timing (15 lbs N + 7.5 lbs S total)
9. R1 + R3 Fertigation - 15 lbs N + 7.5 lbs S at each timing (30 lbs N + 15 lbs S total)
10. R1 + R3 Fertigation – 30 lbs N + 15 lbs S at each timing (60 lbs N + 30 lbs S total)
11. R1 + R3 Fertigation – 45 lbs N + 22.5 lbs S at each timing (90 lbs N + 45 lbs S total)
12. R1 – High fertility (Macro and micro nutrient application broadcast granular) + R3 Fertigation – 30 lbs N + 15 lbs S
13. R1 – Micronutrient foliar application + R1 + R3 Fertigation – 30 lbs N + 15 lbs S at each timing (60 lbs N + 30 lbs S total)

High Fertility Plots. Dry fertilizer was broadcast with a Chabin push spreader at growth stage R1. Nutrients and rates applied included nitrogen at 29 lbs/A, 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. Molybdenum was applied foliarly at 0.043 lbs/A (Moly-16; 11.4 lbs/gal; 3 oz/A) at growth stage R1.

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	5/10/18
Variety	Dyna-Gro 40LL35
Target Seeding Rate/A	140,000
<i>Pesticide Applications</i>	
Canopy 4 oz/A	5/10/18
Liberty 22 oz/A + Dual 1.0 pt/A	6/27/18
Priaxor 6 oz/A + Hero 10.3 oz/A	8/3/18
<i>Harvest Date</i>	10/19/18

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 and 1 week after each fertigation treatment timing (R1, R3, R5) 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	6/8/18
V4	4-trifoliolate	6/15/18
V6	6-trifoliolate	6/20/18
R1	Begin Flower	6/22/18
R2	Full Flower	6/26/18
R3	Begin Pod	7/17/18
R4	Full Pod	7/26/18
R5	Begin Seed	8/6/18
R6	Full Seed	8/24/18
R7	Begin Maturity	9/15/18
R8	Full Maturity	10/1/18

Table 3. Full Season Study 2018 – Fertigation treatment effect on soybean yield and nitrogen and sulfur tissue content.

Fertigation Treatment	Total N + S lbs/A	Yield bu/A	Tissue ¹								
			Nitrogen				Sulfur				
			2018	6/26/18	7/11/18	8/6/18	8/27/18	6/26/18	7/11/18	8/6/18	8/27/18
			%				%				
No fertigation	0 + 0	76 a	4.66 b ²	5.18 ab	5.21 f	4.72 abc	0.27 ab	0.27 g	0.29 de	0.26 bc	
R1	30 + 0	72 a	4.72 ab	5.01 abcde	5.31 ef	4.58 c	0.26 b	0.28 fg	0.29 e	0.26 bc	
R1 + R3	60 + 0	73 a	4.61 b	4.70 de	5.47 bcdef	4.61 bc	0.26 b	0.27 g	0.30 cde	0.25 c	
R1	15 + 7.5	76 a	4.72 ab	4.65 e	5.68 abc	4.62 bc	0.28 a	0.29 def	0.32 bc	0.26 bc	
R1	30 + 15	75 a	4.70 ab	5.00 abcde	5.79 a	4.83 abc	0.27 ab	0.31 cde	0.32 abc	0.27 abc	
R1	60 + 30	75 a	4.66 ab	5.13 abc	5.74 ab	4.83 abc	0.27 ab	0.33 b	0.32 abc	0.29 a	
R1	90 + 45	79 a	4.65 b	5.39 a	5.76 a	4.89 ab	0.27 ab	0.34 b	0.33 ab	0.28 ab	
R1 + R3	15 + 7.5	76 a	4.76 ab	4.96 bcde	5.45 cdef	4.55 c	0.27 ab	0.30 de	0.30 cde	0.25 c	
R1 + R3	30 + 15	78 a	4.67 ab	4.76 cde	5.69 abc	4.74 abc	0.28 a	0.29 ef	0.31 bcd	0.27 abc	
R1 + R3	60 + 30	75 a	4.56 b	5.09 abcd	5.40 def	4.78 abc	0.25 b	0.30 def	0.32 bc	0.27 abc	
R1 + R3	90 + 45	77 a	4.72 ab	5.20 ab	5.68 abc	4.66 abc	0.27 ab	0.32 bc	0.31 bcd	0.27 abc	
R1 + R3 + High fertility	60 + 30	75 a	4.89 a	5.10 abc	5.56 abcde	4.73 abc	0.27 ab	0.38 a	0.34 a	0.28 a	
R1 + R3 + Mo	60 + 30	76 a	4.76 ab	5.00 bcde	5.67 abcd	4.67 abc	0.26 ab	0.31 cd	0.32 abc	0.27 abc	
		NS	NS			NS	NS				
Sufficiency Range ³			4.26 - 5.50					0.18 - 0.30			

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

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

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

Table 4. Full Season Study 2018 – Fertigation treatment effect on soybean phosphorus and potassium tissue content.

Fertigation Treatment	Total N + S lbs/A	Tissue ¹							
		Phosphorus				Potassium			
		6/26/18	7/11/18	8/6/18	8/27/18	6/26/18	7/11/18	8/6/18	8/27/18
		%				%			
No fertigation	0 + 0	0.36 ab ²	0.44 abcd	0.36 a	0.31 abc	3.02 a	2.48 ab	2.12 ab	2.02 a
R1	30 + 0	0.34 ab	0.42 bcdef	0.37 a	0.31 abc	2.98 a	2.41 abc	2.19 ab	1.91 ab
R1 + R3	60 + 0	0.33 ab	0.38 ef	0.35 a	0.31 abc	2.89 a	2.31 cd	2.01 b	1.74 bcd
R1	15 + 7.5	0.35 ab	0.37 f	0.34 a	0.29 cd	2.90 a	2.23 d	2.00 b	1.87 abcd
R1	30 + 15	0.34 ab	0.38 ef	0.36 a	0.30 abcd	2.89 a	2.32 cd	2.11 ab	1.95 ab
R1	60 + 30	0.33 ab	0.39 def	0.35 a	0.30 bcd	2.85 a	2.38 bc	2.12 ab	1.92 ab
R1	90 + 45	0.34 ab	0.45 abc	0.35 a	0.31 abcd	2.96 a	2.43 abc	2.06 ab	1.88 abc
R1 + R3	15 + 7.5	0.36 ab	0.40 cdef	0.35 a	0.30 abcd	2.92 a	2.32 cd	2.06 ab	1.90 ab
R1 + R3	30 + 15	0.36 ab	0.40 cdef	0.37 a	0.31 abcd	2.98 a	2.38 bc	2.13 ab	1.66 d
R1 + R3	60 + 30	0.33 b	0.44 abcde	0.36 a	0.30 abcd	2.84 a	2.39 bc	2.10 ab	1.74 bcd
R1 + R3	90 + 45	0.35 ab	0.23 bcde	0.34 a	0.28 d	2.96 a	2.40 abc	2.07 ab	1.82 abcd
R1 + R3 + High fertility	60 + 30	0.37 a	0.41 cdef	0.35 a	0.29 cd	2.95 a	2.54 a	2.12 ab	1.68 cd
R1 + R3 + Mo	60 + 30	0.33 ab	0.41 cdef	0.37 a	0.29 cd	2.78 a	2.37 bcd	2.18 a	1.83 abcd
		NS		NS	NS	NS		NS	NS
Sufficiency Range ³		0.26 – 0.50				2.00 – 2.80			

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

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

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

Table 5. Full Season Study 2018 – Fertigation treatment effect on soybean magnesium and calcium tissue content.

Fertigation Treatment	Total N + S lbs/A	Tissue ¹							
		Magnesium				Calcium			
		6/26/18	7/11/18	8/6/18	8/27/18	6/26/18	7/11/18	8/6/18	8/27/18
		%				%			
No fertigation	0 + 0	0.28 abc ²	0.30 de	0.31 ab	0.10 c	0.76 bc	0.75 abc	0.89 b	0.93 e
R1	30 + 0	0.27 c	0.29 de	0.33 a	0.15 abc	0.72 c	0.72 bc	0.84 b	1.10 abcde
R1 + R3	60 + 0	0.28 abc	0.29 de	0.31 abc	0.21 a	0.77 bc	0.76 abc	0.84 b	1.17 abcde
R1	15 + 7.5	0.31 ab	0.28 e	0.28 bc	0.12 bc	0.91 abc	0.80 ab	0.90 ab	1.16 abcde
R1	30 + 15	0.29 abc	0.29 de	0.30 abc	0.13 bc	0.75 bc	0.79 abc	0.85 b	1.09 bcde
R1	60 + 30	0.29 abc	0.29 de	0.31 abc	0.15 abc	0.74 bc	0.79 abc	0.87 b	0.99 de
R1	90 + 45	0.28 abc	0.31 bcd	0.29 abc	0.15 abc	0.78 bc	0.83 a	0.89 b	1.09 bcde
R1 + R3	15 + 7.5	0.29 abc	0.29 de	0.28 abc	0.13 bc	0.74 bc	0.78 abc	0.85 b	1.02 cde
R1 + R3	30 + 15	0.29 abc	0.29 de	0.31 abc	0.20 a	1.11 ab	0.79 abc	0.90 ab	1.40 a
R1 + R3	60 + 30	0.28 bc	0.31 cde	0.31 abc	0.18 ab	0.74 bc	0.74 bc	0.93 ab	1.30 abc
R1 + R3	90 + 45	0.28 bc	0.30 de	0.30 abc	0.18 ab	0.71 c	0.79 abc	0.90 b	1.39 ab
R1 + R3 + High fertility	60 + 30	0.31 ab	0.34 ab	0.30 abc	0.20 a	1.17 a	0.77 abc	0.85 b	1.26 abcd
R1 + R3 + Mo	60 + 30	0.27 c	0.29 de	0.33 ab	0.18 ab	0.72 bc	0.79 abc	1.01 a	1.34 ab
		NS		NS		NS	NS	NS	NS
Sufficiency Range ³		0.30 – 0.80				0.50 – 1.50			

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

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

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

Table 6. Full Season Study 2018 – Fertigation treatment effect on soybean boron and manganese tissue content.

Fertigation Treatment	Total N + S lbs/A	Tissue ¹							
		Boron				Manganese			
		6/26/18	7/11/18	8/6/18	8/27/18	6/26/18	7/11/18	8/6/18	8/27/18
		%				%			
No fertigation	0 + 0	37.0 ab ²	37.0 b	43.5 b	25.8 bcd	54 a	57 bc	62 b	46 cd
R1	30 + 0	34.2 b	32.3 d	40.5 bc	25.6 bcd	50 a	54 bc	63 b	79 abcd
R1 + R3	60 + 0	34.0 b	32.8 d	36.8 c	23.3 d	54 a	62 bc	79 b	80 abcd
R1	15 + 7.5	36.5 ab	34.5 bcd	42.0 bc	25.1 bcd	37 a	38 bc	52 b	37 d
R1	30 + 15	36.2 ab	34.0 cd	42.0 bc	25.8 bcd	38 a	47 bc	57 b	31 d
R1	60 + 30	34.7 b	31.8 d	38.3 bc	23.6 cd	54 a	65 b	76 b	80 abcd
R1	90 + 45	36.2 ab	31.8 d	39.8 bc	23.6 cd	42 a	65 b	71 b	50 bcd
R1 + R3	15 + 7.5	36.0 ab	33.0 cd	40.5 bc	24.6 cd	48 a	49 bc	55 b	34 d
R1 + R3	30 + 15	39.0 a	35.8 bc	44.0 b	24.6 cd	61 a	69 b	76 b	113 ab
R1 + R3	60 + 30	34.2 b	31.8 d	40.8 bc	24.3 cd	41 a	50 bc	73 b	79 abcd
R1 + R3	90 + 45	36.5 ab	32.5 d	39.8 bc	25.3 bcd	61 a	64 bc	80 b	104 abc
R1 + R3 + High fertility	60 + 30	35.0 b	42.5 a	53.8 a	29.1 a	50 a	138 a	137 a	138 a
R1 + R3 + Mo	60 + 30	33.7 b	34.0 cd	40.3 bc	26.1 bc	39 a	50 bc	66 b	59 bcd
		NS				NS			
Sufficiency Range ³		21 – 60				25 – 200			

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

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

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

Table 7. Full Season Study 2018 – Fertigation treatment effect on soybean molybdenum and copper tissue content.

Fertigation Treatment	Total N + S lbs/A	Tissue ¹							
		Molybdenum				Copper			
		6/26/18	7/11/18	8/6/18	8/27/18	6/26/18	7/11/18	8/6/18	8/27/18
No fertigation	0 + 0	1.34 a ²	0.64 bc	0.28 bc	0.16 abcd	9.1 b	11.2 e	12.2 a	11.2 a
R1	30 + 0	1.27 a	0.73 bc	0.26 bc	0.16 abcde	9.7 ab	11.7 de	11.9 a	10.8 a
R1 + R3	60 + 0	1.31 a	0.45 c	0.24 bc	0.12 bcdef	8.6 b	11.2 e	13.4 a	11.2 a
R1	15 + 7.5	1.02 ab	0.44 c	0.15 bc	0.17 abc	9.8 ab	12.3 bcd	12.5 a	10.4 ab
R1	30 + 15	0.95 ab	0.43 c	0.17 bc	0.10 cdef	9.1 b	12.0 cde	12.9 a	11.6 a
R1	60 + 30	0.90 ab	0.50 bc	0.18 bc	0.07 def	9.0 b	13.3 a	12.1 a	11.0 a
R1	90 + 45	1.07 ab	0.61 bc	0.12 c	0.054 f	8.8 b	13.3 a	12.8 a	11.0 a
R1 + R3	15 + 7.5	1.13 ab	0.48 c	0.14 c	0.11 cdef	9.6 ab	12.2 bcd	13.0 a	11.1 a
R1 + R3	30 + 15	0.71 b	0.42 c	0.15 bc	0.05 f	11.3 a	13.0 ab	12.1 a	9.7 ab
R1 + R3	60 + 30	0.97 ab	0.68 bc	0.14 c	0.05 f	9.9 ab	12.5 abcd	13.8 a	10.9 a
R1 + R3	90 + 45	0.94 ab	0.51 bc	0.19 bc	0.09 cdef	9.5 ab	12.8 abc	13.4 a	11.3 a
R1 + R3 + High fertility	60 + 30	1.19 ab	2.57 a	0.34 b	0.22 ab	9.5 ab	12.4 bcd	11.8 a	8.6 b
R1 + R3 + Mo	60 + 30	1.17 ab	2.91 a	0.78 a	0.23 a	9.4 ab	12.1 cde	12.4 a	10.7 a
		NS				NS		NS	NS
Sufficiency Range ³		0.21 – 4.00				6 – 20			

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

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

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

Table 8. Full Season Study 2018 – Fertigation treatment effect on soybean iron and zinc tissue content.

Fertigation Treatment	Total N + S lbs/A	Tissue ¹							
		Iron				Zinc			
		6/26/18	7/11/18	8/6/18	8/27/18	6/26/18	7/11/18	8/6/18	8/27/18
		%				%			
No fertigation	0 + 0	80 bc ²	80 c	84 ab	93 ab	73 a	63 cd	70 c	102 abc
R1	30 + 0	84 bc	81 bc	77 b	81 ab	74 a	67 bcd	72 c	104 abc
R1 + R3	60 + 0	100 ab	81 bc	90 a	83 ab	80 a	86 b	104 ab	116 a
R1	15 + 7.5	93 abc	87 ab	80 ab	75 ab	67 a	68 bcd	83 abc	80 abc
R1	30 + 15	87 bc	86 abc	83 ab	81 ab	61 a	73 bcd	77 bc	77 bc
R1	60 + 30	94 abc	86 abc	83 ab	83 ab	60 a	75 bcd	71 c	82 abc
R1	90 + 45	88 bc	90 a	77 b	76 ab	65 a	77 bc	84 abc	72 c
R1 + R3	15 + 7.5	86 bc	83 abc	82 ab	78 ab	56 a	61 cd	68 c	70 c
R1 + R3	30 + 15	111 a	88 a	85 ab	87 a	70 a	70 bcd	76 bc	93 abc
R1 + R3	60 + 30	91 abc	90 a	84 ab	76 ab	59 a	62 cd	89 abc	98 abc
R1 + R3	90 + 45	75 c	87 ab	85 ab	77 ab	63 a	76 bcd	83 abc	106 abc
R1 + R3 + High fertility	60 + 30	86 bc	90 a	81 ab	79 ab	75 a	111 a	111 a	111 ab
R1 + R3 + Mo	60 + 30	92 abc	88 a	82 ab	82 ab	63 a	59 cd	69 c	82 abc
		NS		NS	NS	NS	NS	NS	NS
Sufficiency Range ³		50 – 350				20 – 50			

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

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

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

Table 9. Full Season Study 2018 – Fertigation treatment effect on soybean height.

Fertigation Treatment	Total N + S lbs/A	Height			
		6/27/18	7/11/18	8/9/18	10/19/18
		inches			
No fertigation	0 + 0	10.1 ab ¹	17.1 ab	35.2 a	35.4 abc
R1	30 + 0	9.8 abc	17.1 ab	35.5 a	35.3 abc
R1 + R3	60 + 0	8.8 c	14.7 c	31.8 b	31.4 d
R1	15 + 7.5	9.2 bc	15.6 bc	36.1 a	34.1 abcd
R1	30 + 15	9.6 abc	16.6 abc	36.7 a	33.6 cd
R1	60 + 30	9.8 abc	15.9 abc	35.1 a	34.6 abcd
R1	90 + 45	9.1 bc	16.0 abc	38.0 a	36.9 ab
R1 + R3	15 + 7.5	9.8 abc	16.7 abc	37.4 a	35.2 abc
R1 + R3	30 + 15	9.3 abc	16.3 abc	36.6 a	34.7 abc
R1 + R3	60 + 30	9.4 abc	15.8 abc	35.7 a	35.6 abc
R1 + R3	90 + 45	9.7 abc	17.1 ab	34.9 ab	35.1 abc
R1 + R3 + High fertility	60 + 30	9.3 abc	15.7 abc	35.1 ab	33.9 abcd
R1 + R3 + Mo	60 + 30	10.3 a	17.7 a	38.3 a	37.1 a
		NS	NS	NS	NS

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