

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

**Effect of Fertigation on Irrigated Full Season and Double Cropped Soybeans**

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**Objectives**

- 1) Evaluate the effects of nitrogen and sulfur applied through a center pivot irrigation system on full season and double cropped soybean yield.
- 2) Determine the optimal soybean reproductive growth stage(s) for nitrogen and sulfur applications.

**TWO YEAR AVERAGE YIELD TREND**

In research conducted at the University of Delaware Warrington Irrigation Research Farm in 2015 and 2016, trends in soybean response to nitrogen (N) and sulfur (S) fertigation are developing. Averaged over both years in the full season study, there was an 8 bu/A increase in yield when N + S was applied at the R1 growth stage compared to the no fertigation treatment (*Table 3*). In fact, this treatment resulted in an 8 bu/A increase over the no fertigation treatment in both years and provided the top yield in both years.

Averaged over both years in the double crop study, the largest increase in yield with fertigation over the no fertigation treatment was approximately 3 bu/A (*Table 3*). The top yielding treatments included N + S applied at R5.

**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 no research available on evaluating the response of irrigated soybean to S. Recently, 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.

## **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.

## **MATERIALS AND METHODS**

Two studies were conducted to determine the response of full season and double cropped soybeans to nitrogen plus sulfur fertigation under center pivot irrigation. All of the work for these studies 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.** In both studies, the plots measured 60 ft by 60 ft. Each plot received one of the following fertigation treatments. All treatments were replicated four times.

1. No fertigation (control)
2. R1 fertigation – Nitrogen (30 lbs/A) + Sulfur (15 lbs/A)
3. R3 fertigation – Nitrogen (30 lbs/A) + Sulfur (15 lbs/A)
4. R5 fertigation – Nitrogen (30 lbs/A) + Sulfur (15 lbs/A)
5. R3 + R5 fertigation – Nitrogen applied 2 times (total of 60 lbs/A) + Sulfur applied 2 times (total of 30 lbs/A)
6. R1 + R3 + R5 fertigation – Nitrogen applied 3 times (total of 90 lbs/A) + Sulfur applied 3 times (total of 45 lbs/A)

**Field Operations.** The entire study area was treated identically for all production inputs except nitrogen and sulfur fertigation. Fertilizer was applied based on the University of Delaware recommendations for soybeans. Soybeans in the full season study were planted into conventional tilled soil, whereas the double crop soybean study was planted no-till into wheat stubble following wheat harvest. Both studies were planted with a Monosem planter in 15 inch rows. In the full season study, limited irrigation (>30% soil moisture) will be applied until pod development (R3 to R4) then soil moisture will be maintained at >50% until maturity. In the double cropped study, limited irrigation (>30% soil moisture) will be applied until flowering (R1 to R2) then soil moisture will be maintained at >50% until maturity. Planting dates, soybean varieties, seeding rates, pesticide applications, and harvest dates for both studies are presented in *Table 1*.

**Table 1.** Planting date, variety, seeding rate, pesticide applications, and harvest date for the full season and double crop soybean studies.

<b>Operation</b>	<b>Full Season Study</b>	<b>Double Crop Study</b>
Planting Date	6/3/16	7/12/16
Variety	Asgrow 4135	Asgrow 4135
Target Seeding Rate/A	165,000	200,000
<i>Pesticide Applications</i>		
Canopy 4 oz/A	6/3/16	--
Glyphosate 30 oz/A + Reflex 1.5 pt/A	7/8/16	8/15/16
Gramoxone 1 qt/A + Canopy 4 oz/A	--	7/12/16
Priaxor 6 oz/A + Hero 10.3 oz/A	8/15/16	9/12/16
<i>Harvest Date</i>	10/31/16	11/1/16

*Soil Moisture Monitoring to Trigger Irrigation Treatments.* Soil moisture will be monitored in each study using Watermark soil moisture sensors placed at 4 in., 10 in., and 16 in. below the soil line. Soil moisture data will be transmitted wirelessly approximately 10 times daily from the field to a data logging receiver. Moisture data will be viewed and interpreted daily to determine if irrigation is required. Irrigation will be triggered whenever soil moisture reaches the specific threshold at the 4 in. or 10 in. depth. Weather data will be 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*), plant heights, and NDVI (Normalized Difference Vegetation Index) readings with a handheld Greenseeker were recorded on multiple dates. Lodging was also recorded at harvest. Soil samples were taken 6 inches deep from each plot before fertigation treatments began to determine baseline soil nitrogen levels. Tissue samples were collected 2 weeks 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 the Proc GLM procedure in SAS 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 for the full season and double crop soybean studies.

Growth Stage	Growth Stage Description	Full Season Study	Double Crop Study
		Date	
V2	2-trifoliolate	6/26/16	7/28/16
V4	4-trifoliolate	7/6/16	8/8/16
V6	6-trifoliolate	7/13/16	--
R1	Begin Flower	7/16/16	8/15/16
R2	Full Flower	7/28/16	8/17/16
R3	Begin Pod	8/8/16	8/29/16
R4	Full Pod	8/12/16	9/1/16
R5	Begin Seed	8/17/16	9/7/16
R6	Full Seed	8/31/16	9/23/16
R7	Begin Maturity	9/22/16	10/10/16
R8	Full Maturity	10/10/16	10/20/16

## **RESULTS**

In 2016, the Delaware Soybean Board funded trials to evaluate nitrogen and sulfur fertigation on irrigated full season and double crop soybeans. 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.

Soil samples were taken from all plots at late vegetative stages before fertigation treatments were applied at R1. Soil nitrate levels were very low in both full season and double crop soybean studies and there was no significant difference in levels at this time. In the full season study, soil nitrate levels ranged from 4.70 to 6.55 ppm (*Table 3*). In the double crop study, soil nitrate levels ranged from 3.38 to 3.95 ppm (*Table 4*).

### ***Full Season Study***

In the full season soybean study, yields ranged from 70 to 78 bu/A. The largest yield response was from the R1 treatment where soybeans yielded 8 bu/A greater than the no fertigation treatment (*Table 3*). At maturity, soybean heights ranged from 36 in. to 41.9 in. (*Table 5*). The greatest plant height occurred

when N + S was applied at R1. There were no significant differences observed with NDVI readings on any date.

There were some differences and trends observed in nutrient tissue content. Tissue samples were collected before fertigation treatments were initiated at R1 and 2 weeks after each fertigation timing on 8/1, 8/18, and 9/8. On the 7/18 sample date before fertigation, tissue nitrogen levels ranged from 5.45 to 5.56 ppm (*Table 7*). The largest increase in tissue N concentration was observed when N was applied at R1 and R3. N + S applied at R1 and R3 resulted in the greatest tissue N concentration on the 9/8 sample date.

Tissue sulfur levels were within the sufficiency range or above throughout the season in all treatments (*Table 7*). There were no significant differences observed in tissue S concentrations at any sample date.

Other nutrients to note in this full season study are potassium, magnesium, and molybdenum. These nutrients were found to be below the sufficiency range on at least 1 sample date, which may have limited yield. On the 8/18 sample date, potassium was at the bottom of the sufficiency range and by 9/8 was below the sufficiency range (*Table 7*). Magnesium was at the low end of the sufficiency range on the first 3 sample dates and was below the sufficiency range on the final sample date (*Table 8*). Tissue molybdenum levels were found to be well below the sufficiency range on all sample dates (*Table 9*). This is interesting results that may be worth looking at in the future.

### ***Double Crop Study***

In the double crop soybean study, yields ranged from 51.2 to 55.0 bu/A. All treatments that included an N + S application at R3 or R5 increased yield approximately 2 bu/A over the no fertigation treatment (*Table 4*). N + S applications at the R1 timing yielded 1 bu/A less than the no fertigation treatment. There were no significant differences in plant height on any sample date (*Table 6*). Plant height on 11/4 before harvest ranged from 29.4 to 30.7 in. NDVI was only significant on 9/7, however no trends were apparent.

Tissue samples were collected before fertigation treatments were initiated at R1 and 2 weeks after each fertigation timing on 8/18, 8/24, 9/8, and 9/26. On the 8/18 sample date before fertigation, tissue nitrogen levels ranged from 6.08 to 6.18 ppm (*Table 11*). On 8/18, 8/24, and 9/8, all treatments had N levels above the sufficiency range and on 9/26 N levels were at the lower end of the sufficiency range. There really are not any noticeable trends with tissue N in the fertigation treatments compared to the no fertigation treatment.

Sulfur tissue levels with all treatments were at the top or slightly above the sufficiency range on all tissue sampling dates and no significant differences were observed between any treatments (*Table 11*).

Although there are no trends in the double crop study that the nitrogen + sulfur fertigation influenced potassium, magnesium, and molybdenum tissue levels, it is interesting to note that these three nutrients were below the sufficient range on one or more tissue sample dates (*Table 12; Table 13*). Potassium tissue levels were in the sufficiency range on 8/18 and 8/24, but below the sufficiency range on 9/8 and

9/26 (*Table 12*). Magnesium tissue levels were within the sufficiency range on 8/18 and 8/24, however levels were below the sufficient range on 9/8 and 9/26. Molybdenum tissue levels were well below the sufficiency range on all sample dates (*Table 13*). It is possible that these nutrients may be limiting yield in this study and that it may be necessary to manage these nutrients differently in the future.

**Table 3. Full Season Study** – Fertilization treatment effect on soybean yield and soil nitrogen content before fertilization treatments were initiated.

Fertilization Treatment Timing <sup>1</sup>	Total N + S lbs/A	Yield		Soil <sup>3</sup>			
		2 yr Avg <sup>2</sup>	2015	2016	Nitrate	Ammonium	Nitrate
					7/20/15	7/20/15	7/18/16
No fertilization	0	73.1 c <sup>4</sup>	77 c	70 b	0.85	2.83	4.70
R1	30 + 15	81.7 a	85 a	78 a	1.10	3.15	6.00
R3	30 + 15	76.4 bc	78 bc	74 ab	1.95	2.83	5.33
R5	30 + 15	75.9 bc	78 bc	74 ab	1.18	3.00	5.28
R3 + R5	60 + 30	78.3 ab	82 ab	75 ab	1.68	3.45	6.55
R1 + R3 + R5	90 + 30	77.3 b	78 bc	77 a	1.30	3.05	5.98
LSD <sup>5</sup>			5	NS	NS	NS	NS

<sup>1</sup>Fertilization at each timing included 30 lbs N per acre and 15 lbs S per acre.

<sup>2</sup>Yield data combined from 2015 and 2016.

<sup>3</sup>Soil samples were taken before fertilization treatments were started.

<sup>4</sup>Treatment means followed by the same letter are not significantly different.

<sup>5</sup>Treatments were separated using Fisher's Protected LSD test. NS=not significant.

**Table 4. Double Crop Study** – Fertilization treatment effect on soybean yield and soil nitrogen content before fertilization treatments were initiated.

Fertilization Treatment Timing <sup>1</sup>	Total N + S lbs/A	Yield		Soil <sup>3</sup>			
		2 yr Avg <sup>2</sup>	2015	2016	Nitrate	Ammonium	Nitrate
					8/13/15	8/13/15	8/18/16
No fertilization	0	51.7 bc <sup>4</sup>	50.8 b	52.5 b	3.68	2.70	3.95
R1	30 + 15	51.4 c	51.5 ab	51.2 b	4.48	3.08	3.38
R3	30 + 15	53.0 abc	51.5 ab	54.7 a	4.68	2.88	3.43
R5	30 + 15	54.1 ab	54.0 ab	54.4 ab	4.03	2.80	3.65
R3 + R5	60 + 30	54.2 a	53.5 ab	55.0 a	4.28	2.55	3.73
R1 + R3 + R5	90 + 30	54.5 a	54.3 a	55.0 a	5.23	2.55	3.55
LSD <sup>5</sup>			3.3	NS	NS	NS	NS

<sup>1</sup>Fertilization at each timing included 30 lbs N per acre and 15 lbs S per acre.

<sup>2</sup>Yield data combined from 2015 and 2016.

<sup>3</sup>Soil samples were taken before fertilization treatments were started.

<sup>4</sup>Treatment means followed by the same letter are not significantly different.

<sup>5</sup>Treatments were separated using Fisher's Protected LSD test. NS=not significant.

**Table 5. Full Season Soybean Study** - Fertigation treatment effect on soybean plant height and NDVI.

Fertigation Treatment <sup>1</sup>	Total N + S lbs/A	Plant Height					NDVI <sup>2</sup>			
		7/18/16	8/8/16	8/17/16	8/31/16	10/31/16	7/18/16	8/8/16	8/17/16	8/31/16
No fertigation	0	12.3 a <sup>3</sup>	30.7 a	38.8 b	37.6 b	36.0 b	0.82 ab	0.90 b	0.90 a	0.85 b
R1	30 + 15	13.1 a	33.5 a	42.2 a	41.8 a	41.9 a	0.85 a	0.91 a	0.91 a	0.89 a
R3	30 + 15	12.7 a	31.5 a	39.8 ab	39.6 ab	39.0 ab	0.82 ab	0.91 ab	0.91 a	0.87 ab
R5	30 + 15	12.4 a	31.7 a	38.4 b	39.7 ab	36.6 b	0.84 a	0.90 b	0.91 a	0.88 a
R3 + R5	60 + 30	12.0 a	30.5 a	38.8 b	37.7 b	37.6 b	0.78 b	0.90 b	0.91 a	0.88 ab
R1 + R3 + R5	90 + 30	12.6 a	32.2 a	39.8 ab	39.9 ab	38.3 b	0.81 ab	0.91 ab	0.91 a	0.89 a
LSD		NS	NS	NS	NS		NS	NS	NS	NS

<sup>1</sup>Fertigation at each timing included 30 lbs N per acre and 15 lbs S per acre.

<sup>2</sup>NDVI (Normalized Difference Vegetation Index). NDVI of 0 = no vegetation (minimum); 1 = full vegetation (maximum).

<sup>3</sup>Treatment means followed by the same letter are not significantly different.

**Table 6. Double Crop Soybean Study** - Fertigation treatment effect on soybean plant height and NDVI.

Fertigation Treatment <sup>1</sup>	Total N + S lbs/A	Plant Height					NDVI <sup>2</sup>			
		8/17/16	8/29/16	9/7/16	9/23/16	10/31/16	8/17/16	8/29/16	9/7/16	9/23/16
No fertigation	0	12.9 a <sup>3</sup>	24.0 a	30.8 a	30.3 a	29.4 a	0.81 a	0.89 a	0.89 b	0.89 a
R1	30 + 15	13.1 a	23.7 a	30.8 a	30.3 a	30.1 a	0.83 a	0.89 a	0.89 b	0.90 a
R3	30 + 15	13.0 a	24.0 a	30.0 a	30.6 a	29.7 a	0.84 a	0.89 a	0.89 b	0.89 a
R5	30 + 15	13.6 a	24.3 a	30.2 a	30.9 a	30.0 a	0.83 a	0.90 a	0.89 b	0.89 a
R3 + R5	60 + 30	13.4 a	24.7 a	30.9 a	31.3 a	30.3 a	0.84 a	0.90 a	0.91 a	0.89 a
R1 + R3 + R5	90 + 30	13.0 a	23.2 a	30.2 a	30.9 a	30.7 a	0.85 a	0.90 a	0.90 b	0.90 a
LSD		NS	NS	NS	NS	NS	NS	NS		NS

<sup>1</sup>Fertigation at each timing included 30 lbs N per acre and 15 lbs S per acre.

<sup>2</sup>NDVI (Normalized Difference Vegetation Index). NDVI of 0 = no vegetation (minimum); 1 = full vegetation (maximum).

<sup>3</sup>Treatment means followed by the same letter are not significantly different.



**Table 7. Full Season Soybean Study** - Fertigation treatment effect on leaf tissue nitrogen, sulfur, and phosphorus on multiple dates.

Fertigation Treatment	Total N + S lbs/A	Tissue <sup>1</sup>											
		Nitrogen				Sulfur				Phosphorus			
		7/18/16	8/1/16	8/18/16	9/8/16	7/18/16	8/1/16	8/18/16	9/8/16	7/18/16	8/1/16	8/18/16	9/8/16
No fertigation	0	5.54 a <sup>2</sup>	5.91 a	6.16 ab	4.67 b	0.30 a	0.29 ab	0.34 a	0.26 a	0.46 a	0.45 a	0.46 ab	0.31 bc
R1	30 + 15	5.52 a	6.12 a	6.31 ab	4.82 a	0.30 a	0.30 ab	0.35 a	0.27 a	0.47 a	0.56 a	0.47 ab	0.31 bc
R3	30 + 15	5.45 a	6.13 a	6.49 a	4.68 ab	0.29 a	0.29 ab	0.33 a	0.26 a	0.45 a	0.52 a	0.44 b	0.29 c
R5	30 + 15	5.51 a	5.89 a	5.93 b	4.55 b	0.30 a	0.29 ab	0.34 a	0.26 a	0.45 a	0.46 a	0.46 ab	0.35 a
R3 + R5	60 + 30	5.56 a	6.01 a	6.42 a	4.77 ab	0.30 a	0.28 b	0.35 a	0.27 a	0.48 a	0.51 a	0.48 a	0.33 b
R1 + R3 + R5	90 + 30	5.56 a	6.07 a	6.51 a	4.77 ab	0.30 a	0.30 a	0.35 a	0.28 a	0.50 a	0.51 a	0.48 a	0.32 b
LSD													
Sufficiency Range <sup>3</sup>		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		4.26 - 5.50				0.18 - 0.30				0.26 - 0.50			

<sup>1</sup>Tissue samples were collected 2 weeks after each fertigation timing.

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

<sup>3</sup>Sufficiency range = Expected normal or sufficient range in nutrient concentration.

**Table 8. Full Season Soybean Study** - Fertigation treatment effect on leaf tissue potassium, magnesium, and calcium on multiple dates.

Fertigation Treatment	Total N + S lbs/A	Tissue <sup>1</sup>											
		Potassium				Magnesium				Calcium			
		7/18/16	8/1/16	8/18/16	9/8/16	7/18/16	8/1/16	8/18/16	9/8/16	7/18/16	8/1/16	8/18/16	9/8/16
No fertigation	0	2.80 a <sup>2</sup>	2.14 a	2.03 a	1.84 a	0.36 ab	0.34 ab	0.36 a	0.16 ab	0.83 a	0.80 ab	0.85 a	1.28 a
R1	30 + 15	2.84 a	2.28 a	2.08 a	1.80 a	0.36 ab	0.34 ab	0.34 a	0.15 ab	0.85 a	0.75 b	0.85 a	1.28 a
R3	30 + 15	2.72 a	2.24 a	2.04 a	1.76 a	0.34 b	0.36 a	0.34 a	0.16 ab	0.86 a	0.77 ab	0.90 a	1.28 a
R5	30 + 15	2.75 a	2.18 a	2.03 a	1.86 a	0.35 ab	0.33 b	0.34 a	0.15 b	0.86 a	0.84 a	0.89 a	1.39 a
R3 + R5	60 + 30	2.82 a	2.24 a	2.10 a	1.85 a	0.36 ab	0.36 ab	0.36 a	0.16 ab	0.81 a	0.79 ab	0.94 a	1.38 a
R1 + R3 + R5	90 + 30	2.83 a	2.32 a	2.11 a	1.73 a	0.38 a	0.35 ab	0.36 a	0.18 a	0.84 a	0.78 ab	0.92 a	1.46 a
LSD													
Sufficiency Range <sup>3</sup>		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2.00 - 2.80				0.30 - 0.80				0.50 - 1.50			

<sup>1</sup>Tissue samples were collected 2 weeks after each fertigation timing.

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

<sup>3</sup>Sufficiency range = Expected normal or sufficient range in nutrient concentration.

**Table 9. Full Season Soybean Study** - Fertigation treatment effect on leaf tissue boron, manganese, and molybdenum on multiple dates.

Fertigation Treatment	Total N + S lbs/A	Tissue <sup>1</sup>											
		Boron				Manganese				Molybdenum			
		7/18/16	8/1/16	8/18/16	9/8/16	7/18/16	8/1/16	8/18/16	9/8/16	7/18/16	8/1/16	8/18/16	9/8/16
No fertigation	0	38.0 a <sup>2</sup>	37.0 abc	39.3 a	26.8 a	49.3 ab	49.8 abc	51.3 b	52.0 b	0.06 ab	0.08 bc	0.13 a	0.22 ab
R1	30 + 15	38.3 a	36.3 bc	41.0 a	25.8 ab	50.3 ab	45.0 c	51.5 b	64.8 ab	0.13 a	0.31 a	0.10 a	0.12 b
R3	30 + 15	37.5 a	36.5 abc	38.5 a	25.8 ab	44.5 b	55.0 a	54.0 ab	68.5 a	0.03 b	0.01 c	0.08 a	0.23 a
R5	30 + 15	37.0 a	37.8 ab	40.0 a	25.8 ab	47.3 ab	55.0 a	61.8 a	76.3 a	0.04 ab	0.02 c	0.07 a	0.23 a
R3 + R5	60 + 30	38.0 a	35.3 c	41.0 a	25.3 b	55.3 a	53.8 ab	57.3 ab	70.5 a	0.06 ab	0.08 bc	0.18 a	0.16 ab
R1 + R3 + R5	90 + 30	38.5 a	38.8 a	42.0 a	25.5 b	55.5 a	46.5 bc	52.3 b	65.5 ab	0.13 a	0.18 ab	0.18 a	0.22 ab
LSD													
Sufficiency Range <sup>3</sup>		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		21 - 60				25 - 200				0.21 - 4.00			

<sup>1</sup>Tissue samples were collected 2 weeks after each fertigation timing.

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

<sup>3</sup>Sufficiency range = Expected normal or sufficient range in nutrient concentration.

**Table 10. Full Season Soybean Study** - Fertigation treatment effect on leaf tissue copper, iron, and zinc on multiple dates.

Fertigation Treatment	Total N + S lbs/A	Tissue <sup>1</sup>											
		Copper				Iron				Zinc			
		7/18/16	8/1/16	8/18/16	9/8/16	7/18/16	8/1/16	8/18/16	9/8/16	7/18/16	8/1/16	8/18/16	9/8/16
No fertigation	0	13.7 a <sup>2</sup>	10.4 ab	9.6 bc	9.6 ab	91.8 a	84.5 a	90.8 a	80.5 a	74.0 a	65.3 ab	67.0 b	75.8 b
R1	30 + 15	14.4 a	9.8 ab	10.3ab	9.3 bc	78.3 a	82.0 a	92.5 a	83.5 a	71.5 a	57.5 b	68.0 b	75.0 b
R3	30 + 15	11.7 a	9.8 ab	9.2 c	8.7 c	80.5 a	84.0 a	91.5 a	76.8 a	69.3 a	58.5 b	62.5 b	70.5 b
R5	30 + 15	12.0 a	11.0 ab	10.9 a	10.0 a	85.8 a	87.0 a	92.3 a	81.0 a	74.3 a	76.0 a	83.5 a	114.5 a
R3 + R5	60 + 30	11.9 a	9.5 b	9.7 bc	8.8 c	80.3 a	81.8 a	92.8 a	79.0 a	77.8 a	60.0 b	69.5 b	85.8 b
R1 + R3 + R5	90 + 30	14.7 a	10.1 ab	9.6 bc	9.1 bc	81.0 a	83.3 a	83.0 a	84.0 a	76.3 a	62.5 ab	69.8 b	83.5 b
LSD													
Sufficiency Range <sup>3</sup>		NS	NS			NS	NS	NS	NS	NS	NS		
		6 - 20				50 - 350				20 - 50			

<sup>1</sup>Tissue samples were collected 2 weeks after each fertigation timing.

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

<sup>3</sup>Sufficiency range = Expected normal or sufficient range in nutrient concentration.

**Table 11. Double Crop Soybean Study** - Fertigation treatment effect on leaf tissue nitrogen, sulfur, and phosphorus on multiple dates.

Fertigation Treatment	Total N + S lbs/A	Tissue <sup>1</sup>											
		Nitrogen				Sulfur				Phosphorus			
		8/18/16	8/24/16	9/8/16	9/26/16	8/18/16	8/24/16	9/8/16	9/26/16	8/18/16	8/24/16	9/8/16	9/26/16
No fertigation	0	6.16 a <sup>2</sup>	6.37 c	5.93 a	4.37 ab	0.34 a	0.33 a	0.29 ab	0.25 a	0.50 a	0.55 a	0.38 a	0.33 a
R1	30 + 15	6.16 a	6.55 bc	5.78 a	4.33 b	0.34 a	0.34 a	0.25 b	0.25 a	0.48 a	0.59 a	0.35 a	0.34 a
R3	30 + 15	6.08 a	6.64 b	5.95 a	4.37 ab	0.35 a	0.34 a	0.28 ab	0.25 a	0.47 a	0.59 a	0.38 a	0.32 a
R5	30 + 15	6.18 a	6.55 bc	5.88 a	4.47 a	0.34 a	0.34 a	0.29 a	0.27 a	0.49 a	0.54 a	0.36 a	0.34 a
R3 + R5	60 + 30	6.13 a	6.60 bc	5.91 a	4.40 ab	0.34 a	0.34 a	0.28 ab	0.26 a	0.48 a	0.58 a	0.36 a	0.33 a
R1 + R3 + R5	90 + 30	6.18 a	6.94 a	5.76 a	4.31 b	0.35 a	0.35 a	0.28 ab	0.26 a	0.49 a	0.60 a	0.37 a	0.35 a
LSD													
Sufficiency Range <sup>3</sup>		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		4.26 - 5.50				0.18 - 0.30				0.26 - 0.50			

<sup>1</sup>Tissue samples were collected 2 weeks after each fertigation timing.

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

<sup>3</sup>Sufficiency range = Expected normal or sufficient range in nutrient concentration.

**Table 12. Double Crop Soybean Study** - Fertigation treatment effect on leaf tissue potassium, magnesium, and calcium on multiple dates.

Fertigation Treatment	Total N + S lbs/A	Tissue <sup>1</sup>											
		Potassium				Magnesium				Calcium			
		8/18/16	8/24/16	9/8/16	9/26/16	8/18/16	8/24/16	9/8/16	9/26/16	8/18/16	8/24/16	9/8/16	9/26/16
No fertigation	0	2.58 a <sup>2</sup>	2.51 a	1.90 ab	1.58 ab	0.41 a	0.35 a	0.20 a	0.12 b	0.88 a	0.78 a	0.73 a	1.10 b
R1	30 + 15	2.53 a	2.55 a	1.75 b	1.47 b	0.38 a	0.35 a	0.20 a	0.14 ab	0.85 a	0.80 a	0.68 a	1.14 b
R3	30 + 15	2.51 a	2.54 a	1.93 ab	1.52 ab	0.38 a	0.37 a	0.21 a	0.14 ab	0.87 a	0.81 a	0.74 a	1.17 ab
R5	30 + 15	2.52 a	2.54 a	1.95 a	1.64 a	0.41 a	0.35 a	0.21 a	0.12 b	0.86 a	0.77 a	0.72 a	1.12 b
R3 + R5	60 + 30	2.51 a	2.43 a	1.87 ab	1.50 ab	0.39 a	0.36 a	0.21 a	0.14 ab	0.87 a	0.81 a	0.76 a	1.23 ab
R1 + R3 + R5	90 + 30	2.53 a	2.52 a	1.86 ab	1.47 ab	0.40 a	0.36 a	0.21 a	0.16 a	0.88 a	1.25 a	0.76 a	1.28 a
LSD													
Sufficiency Range <sup>3</sup>		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		2.00 - 2.80				0.30 - 0.80				0.50 - 1.50			

<sup>1</sup>Tissue samples were collected 2 weeks after each fertigation timing.

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

<sup>3</sup>Sufficiency range = Expected normal or sufficient range in nutrient concentration.

**Table 13. Double Crop Soybean Study** - Fertigation treatment effect on leaf tissue boron, manganese, and molybdenum on multiple dates.

Fertigation Treatment	Total N + S lbs/A	Tissue <sup>1</sup>											
		Boron				Manganese				Molybdenum			
		8/18/16	8/24/16	9/8/16	9/26/16	8/18/16	8/24/16	9/8/16	9/26/16	8/18/16	8/24/16	9/8/16	9/26/16
No fertigation	0	39.8 a <sup>2</sup>	38.5 a	32.8 a	21.0 a	79.0 a	77.0 b	74.8 b	110.3 c	0.12 a	0.06 a	0.14 a	0.05 a
R1	30 + 15	38.5 a	36.8 a	30.5 a	21.0 a	90.0 a	81.5 ab	86.8 b	146.5 abc	0.10 a	0.07 a	0.17 a	0.05 a
R3	30 + 15	40.3 a	38.5 a	33.3 a	21.0 a	88.0 a	87.3 ab	87.5 b	125.3 bc	0.09 a	0.03 a	0.15 a	0.09 a
R5	30 + 15	38.3 a	37.5 a	32.3 a	21.5 a	88.0 a	89.3 ab	91.0 b	147.3 abc	0.07 a	0.03 a	0.12 a	0.13 a
R3 + R5	60 + 30	38.8 a	37.5 a	30.5 a	20.8 a	92.8 a	105.8 a	115.0 a	185.0 a	0.09 a	0.03 a	0.13 a	0.07 a
R1 + R3 + R5	90 + 30	39.3 a	36.8 a	30.5 a	21.5 a	95.3 a	98.3 a	90.0 b	167.0 a	0.08 a	0.06 a	0.08 a	0.06 a
LSD													
Sufficiency Range <sup>3</sup>		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		21 - 60				25 - 200				0.21 - 4.00			

<sup>1</sup>Tissue samples were collected 2 weeks after each fertigation timing.

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

<sup>3</sup>Sufficiency range = Expected normal or sufficient range in nutrient concentration.

**Table 14. Double Crop Soybean Study** - Fertigation treatment effect on leaf tissue copper, iron, and zinc on multiple dates.

Fertigation Treatment	Total N + S lbs/A	Tissue <sup>1</sup>											
		Copper				Iron				Zinc			
		8/18/16	8/24/16	9/8/16	9/26/16	8/18/16	8/24/16	9/8/16	9/26/16	8/18/16	8/24/16	9/8/16	9/26/16
No fertigation	0	12.0 ab <sup>2</sup>	10.3 b	8.7 a	7.5 b	85.8 a	80.5 a	79.5 a	70.0 a	93.0 b	76.0 d	80.0 b	92.3 c
R1	30 + 15	10.7 b	10.9 ab	8.4 a	8.9 a	85.8 a	82.3 ab	74.3 a	67.8 a	113.8 a	99.0 ab	98.8 ab	154.5 a
R3	30 + 15	12.4 ab	10.1 b	8.9 a	8.0 ab	90.3 a	79.3 ab	83.8 a	70.5 a	113.3 a	85.8 bcd	97.3 ab	126.0 abc
R5	30 + 15	11.6 ab	10.4 b	9.6 a	8.6 ab	84.0 a	76.5 b	82.3 a	73.5 a	91.8 b	79.3 cd	81.8 b	104.5 bc
R3 + R5	60 + 30	13.7 a	10.2 b	9.6 a	8.2 ab	88.3 a	82.0 ab	83.0 a	70.5 a	108.5 ab	95.0 abc	106.8 a	140.0 ab
R1 + R3 + R5	90 + 30	12.1 ab	11.9 a	9.5 a	9.1 a	89.3 a	86.5 a	81.8 a	70.5 a	111.3 ab	107.0 a	108.8 a	155.0 a
LSD													
Sufficiency Range <sup>3</sup>		NS	NS	NS	NS	NS	NS	NS	NS	NS			
		6 - 20				50 - 350				20 - 50			

<sup>1</sup>Tissue samples were collected 2 weeks after each fertigation timing.

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

<sup>3</sup>Sufficiency range = Expected normal or sufficient range in nutrient concentration.