Final Report to Delaware Soybean Board

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.

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.

In a preliminary replicated study conducted at the University of Delaware Warrington Irrigation Research Farm in 2014, nitrogen + sulfur (30 lbs N/A + 8 lbs S/A) was fertigated on full season soybeans at R5. Soybeans in plots that received the fertigation yielded 5 bu/A greater than plots that received no fertigation.

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.

Operation	Full Season Study	Double Crop Study
Planting Date	5/27/15	7/8/15
Variety	Asgrow 4232	Asgrow 4232
Target Seeding Rate/A	155,000	200,000
Pesticide Applications		
Canopy 4 oz/A	5/27/15	--
Glyphosate 30 oz/A + Canopy 4 oz/A	--	7/8/15
Glyphosate 30 oz/A + Reflex 1.5 pt/A	6/24/15	8/10/15
Priaxor 6 oz/A + Hero 10.3 oz/A	8/14/15	--
Harvest Date	11/16/15	11/16/15

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	6/19/15	7/28/15
V4	4-trifoliolate	7/1/15	8/7/15
V6	6-trifoliolate	7/7/15	--
R1	Begin Flower	7/8/15	8/17/15
R2	Full Flower	7/11/15	8/19/15
R3	Begin Pod	7/24/15	8/24/15
R4	Full Pod	8/4/15	9/2/15
R5	Begin Seed	8/16/15	9/8/15
R6	Full Seed	9/2/15	9/18/15
R7	Begin Maturity	9/25/15	10/20/15
R8	Full Maturity	10/7/15	11/5/15

RESULTS

In 2015, 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 and ammonium 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 and ammonium levels ranged from 0.85 to 1.95 ppm and 2.83 to 3.45 ppm, respectively (*Table 3*). In the double crop study, soil nitrate and ammonium levels ranged from 3.68 to 5.23 ppm and 2.55 to 3.08 ppm, respectively (*Table 4*).

Full Season Study

In the full season soybean study, yields ranged from 77 to 85 bu/A. The largest yield response was from the R1 treatment and the R3 + R5 treatment where soybeans yielded 8 bu/A and 5 bu/A, respectively, greater than the no fertigation treatment (*Table 3*). There was only a 1 bu/A increase over the no fertigation treatment when N + S was applied at R3, R5, and R1 + R3 + R5. There were no significant differences in plant height or NDVI on any sample date (*Table 5*). Plant height on 11/4 before harvest ranged from 42 to 45".

There were some differences and trends observed in nutrient tissue content. Tissue samples were collected 2 weeks after each fertigation timing on 7/27, 8/12, and 9/2. On the 7/27 sample date, all treatments had nitrogen levels above the sufficient range (*Table 7*). However, nitrogen concentration was noticeably higher with the two treatments that received fertigation at R1 than all other treatments. This trend was also noticeable on the 8/12 sample date. The R1 timing seemed to have the greatest effect on tissue nitrogen levels than any other timing. Surprisingly, tissue nitrogen levels on the 9/2 sample date were similar across all treatments, which ranged from 4.86 to 4.97%.

Tissue sulfur levels were within the sufficient range or slightly above throughout the season in all treatments (*Table 7*). There was a noticeable trend on 7/27 that plots receiving the R1 application were slightly higher than all others. On 8/12, there were no significant differences between treatments; however, there was a trend that all treatments that had received fertigation up to this date were slightly higher and above the sufficient range. On the 9/2, all fertigated treatments, except the R5 only application, had significantly higher sulfur levels than the non-treated.

Other nutrients to note in this full season study that may have been influenced by nitrogen + sulfur fertigation are boron, manganese, molybdenum, and zinc. Boron was in the sufficient range in all plots on all sample dates (*Table 9*). However, on all sample dates there was a trend that treatments that received fertigation at the R1 timing had slightly lower boron levels than all other treatments. Manganese levels were in the sufficient range in all plots on all sample dates. However, on the 9/2 sample date, the two treatments that received the R1 timing resulted in the highest tissue manganese levels. Tissue molybdenum levels were within the sufficient range on 7/27 and 8/12, but on 9/2 tissue levels were very low in all treatments. There was a trend that molybdenum levels in the two treatments that included the R1 timing had the lowest levels, however, all fertigated treatments trended lower than the non-treated. Tissue zinc levels trended higher with all fertigated treatments compared to the non-treated (*Table 10*). These are interesting trends that may be worth looking at in the future.

Although there are no trends that the nitrogen + sulfur fertigation influenced potassium and magnesium tissue levels, it is interesting to note that these two nutrients were below the sufficient range on one or more tissue sample dates (*Table 8*). Potassium tissue levels were in the sufficient range on 7/27 and 8/12, however, levels were slightly below the sufficient range on 9/2. Magnesium was slightly within the sufficient range on 7/27; however, levels declined considerably below the sufficient range by 9/2 (*Table 8*). 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.

Double Crop Study

In the double crop soybean study, yields ranged from 51 to 54 bu/A. All treatments that included an N + S application at R5 increased yield approximately 3 bu/A over the no fertigation treatment (*Table 4*). N + S applications at the R1 and R3 timings increased yield <1 bu/A over 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 36 to 37". NDVI was only significant on 8/25, however no trends were apparent.

There were some differences and trends observed in nutrient tissue content. Tissue samples were collected 2 weeks after each fertigation timing on 8/27, 9/10, and 10/7. On 8/27 and 9/10, all treatments had nitrogen levels above the sufficient range (*Table 11*). On 8/27, tissue nitrogen levels with the two treatments that were treated at R1 trended higher than all other treatments. On 9/10, treatments that received the R3 treatment trended slightly higher than all other treatments. On 10/7, all treatments had tissue nitrogen levels below the sufficient range. There were no significant differences between treatments on 10/7, however there was a trend. The no fertigation treatment had the highest tissue nitrogen levels and the R1 treatments had the lowest.

Sulfur tissue levels with all treatments were at or slightly above the sufficient range on all tissue sampling dates and only had significant differences between treatments on 9/10 (*Table 11*). However on 9/10, there were no trends apparent between treatments.

Other nutrients to note in this double crop study that may have been influenced by nitrogen + sulfur fertigation are calcium, manganese, and zinc. All treatments had calcium tissue levels in the sufficient range on all sample dates and there were no significant differences between treatments on either sample date (*Table 12*). There was a trend on 10/7 that calcium tissue levels in all fertigated treatments (1.34 to 1.55%) were higher than the level in the no fertigation treatment (1.09%). Manganese levels were in the sufficient range in all plots on all sample dates (*Table 13*). There was a trend on 10/7 where the no fertigation treatment resulted in the lowest manganese levels and the two treatments that had multiple fertigations were the highest. Tissue zinc levels trended higher with all fertigated treatments compared to the non-treated on 10/7 (*Table 14*). The R1+R3+R5 treatment had a significantly higher zinc level on this date than any other treatment. These are interesting trends that may be worth looking at in the future.

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 sufficient range on 8/27, at or slightly below the sufficient range on 9/2, and below the sufficient range on 10/7 (*Table 12*). Magnesium tissue levels were within the sufficient range on 8/27, however levels were below the sufficient range on 9/10 and 10/7. Molybdenum tissue levels were well below the sufficient 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 – Fertigation treatment effect on soybean yield and soil nitrogen content before fertigation treatments were initiated

Fertigation Treatment Timing[1]	Total N + S	Yield	Soil[2] Nitrate 7/20/15	Soil[2] Ammonium 7/20/15
	lbs/A	bu/A	ppm	
No fertigation	0	77 c[4]	0.85	2.83
R1	30 + 15	85 a	1.10	3.15
R3	30 + 15	78 bc	1.95	2.83
R5	30 + 15	78 bc	1.18	3.00
R3 + R5	60 + 30	82 ab	1.68	3.45
R1 + R3 + R5	90 + 30	78 bc	1.30	3.05
LSD[5]		5	NS	NS

[1]Fertigation at each timing included 30 lbs N per acre and 15 lbs S per acre.
[2]Soil samples were taken before fertigation treatments were started.
[3]Tissue samples were collected 2 weeks after each fertigation timing.
[4]Treatment means followed by the same letter are not significantly different.
[5]Treatments were separated using Fisher's Protected LSD test. NS=not significant.

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

Fertigation Treatment Timing[1]	Total N + S	Yield	Soil[2] Nitrate 8/13/15	Soil[2] Ammonium 8/13/15
	lbs/A	bu/A	ppm	
No fertigation	0	50.8 b[4]	3.68	2.70
R1	30 + 15	51.5 ab	4.48	3.08
R3	30 + 15	51.5 ab	4.68	2.88
R5	30 + 15	54.0 ab	4.03	2.80
R3 + R5	60 + 30	53.5 ab	4.28	2.55
R1 + R3 + R5	90 + 30	54.3 a	5.23	2.55
LSD[5]		3.3	NS	NS

[1]Fertigation at each timing included 30 lbs N per acre and 15 lbs S per acre.
[2]Soil samples were taken before fertigation treatments were started.
[3]Tissue samples were collected 2 weeks after each fertigation timing.
[4]Treatment means followed by the same letter are not significantly different.
[5]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.

Irrigation Treatment[1]	Total N + S	Plant Height				NDVI[2]			
		7/21/2015	8/6/2015	8/25/2015	11/4/2015	7/13/2015	7/21/2015	8/6/2015	8/25/2015
	lbs/A	%							
No fertigation	0	20.3 ab[3]	36.7 a	41.5 a	42.7 a	0.88 abc	0.91 a	0.92 a	0.89 b
R1	30 + 15	22.1 a	37.8 a	43.9 a	43.0 a	0.89 ab	0.92 a	0.91 ab	0.91 a
R3	30 + 15	20.0 ab	36.9 a	43.1 a	42.7 a	0.87 bc	0.91 a	0.92 a	0.90 ab
R5	30 + 15	20.4 ab	36.5 a	42.0 a	41.9 a	0.88 abc	0.91 a	0.90 b	0.89 b
R3 + R5	60 + 30	22.0 a	38.3 a	43.6 a	44.5 a	0.89 ab	0.92 a	0.92 a	0.90 ab
R1 + R3 + R5	90 + 30	18.8 b	36.3 a	42.5 a	42.2 a	0.86 c	0.92 a	0.92 a	0.91 a
LSD		3.2	3.6	4.0	3.6	0.03	0.02	0.01	0.01
		NS	NS	NS	NS	NS	NS	NS	NS

[1]Treatments with limited irrigation were kept at >30% available soil moisture (0% moisture = dry; 100% moisture = wet).

[2]NDVI (Normalized Difference Vegetation Index). NDVI of 0 = no vegetation (minimum); 1 = full vegetation (maximum).

[3]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.

Irrigation Treatment[1]	Total N + S	Plant Height				NDVI[2]		
		8/14/2015	8/25/2015	9/11/2015	11/4/2015	8/14/2015	8/25/2015	9/11/2015
	lbs/A	%						
No fertigation	0	12.9 a[3]	23.1 a	37.4 a	35.7 a	0.78 a	0.89 bc	0.91 a
R1	30 + 15	13.3 a	23.0 a	37.1 a	36.7 a	0.77 a	0.90 ab	0.91 a
R3	30 + 15	13.9 a	23.5 a	37.3 a	36.8 a	0.79 a	0.90 bc	0.90 a
R5	30 + 15	13.5 a	24.4 a	37.5 a	37.1 a	0.79 a	0.90 ab	0.91 a
R3 + R5	60 + 30	13.5 a	22.6 a	37.0 a	37.0 a	0.79 a	0.89 c	0.91 a
R1 + R3 + R5	90 + 30	13.4 a	24.6 a	37.8 a	36.8 a	0.79 a	0.91 a	0.91 a
LSD		1.5	3.2	5.2	3.9	0.05	0.01	0.01
		NS	NS	NS	NS	NS		NS

[1]Treatments with limited irrigation were kept at >30% available soil moisture (0% moisture = dry; 100% moisture = wet).

[2]NDVI (Normalized Difference Vegetation Index). NDVI of 0 = no vegetation (minimum); 1 = full vegetation (maximum).

[3]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.

		Tissue[1]								
Irrigation	Total	Nitrogen			Sulfur			Phosphorus		
Treatment	N + S	7/27/2015	8/12/2015	9/2/2015	7/27/2015	8/12/2015	9/2/2015	7/27/2015	8/12/2015	9/2/2015
	lbs/A	%			%			%		
No fertigation	0	5.98 bc[2]	5.21 bc	4.93 a	0.26 b	0.29 bc	0.26 b	0.47 ab	0.34 a	0.29 a
R1	30 + 15	6.57 a	5.50 ab	4.86 a	0.30 a	0.31 abc	0.28 a	0.57 a	0.36 a	0.28 a
R3	30 + 15	5.80 c	5.15 bc	4.97 a	0.25 b	0.33 ab	0.28 a	0.46 b	0.34 a	0.29 a
R5	30 + 15	6.00 bc	5.05 c	4.85 a	0.26 b	0.28 c	0.26 b	0.48 ab	0.33 a	0.28 a
R3 + R5	60 + 30	6.10 bc	5.32 abc	4.94 a	0.27 b	0.32 abc	0.28 a	0.53 ab	0.38 a	0.30 a
R1 + R3 + R5	90 + 30	6.41 ab	5.69 a	4.96 a	0.31 a	0.34 a	0.29 a	0.47 ab	0.37 a	0.29 a
LSD		0.45	0.38	0.2	0.02	0.05	0.012	0.11	0.05	0.04
				NS		NS		NS	NS	NS
Sufficiency Range[3]		4.26 - 5.50			0.18 – 0.30			0.26 - 0.50		

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

		Tissue[1]								
Irrigation	Total	Potassium			Magnesium			Calcium		
Treatment	N + S	7/27/2015	8/12/2015	9/2/2015	7/27/2015	8/12/2015	9/2/2015	7/27/2015	8/12/2015	9/2/2015
	lbs/A	%			%			%		
No fertigation	0	2.25 a[2]	2.13 a	1.82 ab	0.32 a	0.27 a	0.13 a	0.74 b	1.25 a	1.16 a
R1	30 + 15	2.28 a	2.11 a	1.65 b	0.34 a	0.26 a	0.15 a	0.72 bc	1.11 a	1.31 a
R3	30 + 15	2.34 a	2.08 a	1.91 a	0.32 a	0.27 a	0.13 a	0.79 a	1.26 a	1.13 a
R5	30 + 15	2.22 a	2.10 a	1.83 ab	0.33 a	0.25 a	0.13 a	0.75 b	1.23 a	1.23 a
R3 + R5	60 + 30	2.32 a	2.03 a	1.79 ab	0.33 a	0.27 a	0.15 a	0.74 b	1.21 a	1.37 a
R1 + R3 + R5	90 + 30	2.24 a	2.06 a	1.74 ab	0.31 a	0.27 a	0.14 a	0.68 c	1.07 a	1.23 a
LSD		0.14	0.2	0.2	0.04	0.04	0.04	0.04	0.19	0.31
		NS	NS	NS	NS	NS	NS		NS	NS
Sufficiency Range[3]		2.00 – 2.80			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 9. Full Season Soybean Study - Fertigation treatment effect on leaf tissue boron, manganese, and molybdenum on multiple dates.

Irrigation Treatment	Total N + S	Tissue[1]								
		Boron			Manganese			Molybdenum		
		7/27/2015	8/12/2015	9/2/2015	7/27/2015	8/12/2015	9/2/2015	7/27/2015	8/12/2015	9/2/2015
	lbs/A	ppm			ppm			ppm		
No fertigation	0	35.3 a[2]	36.3 a	29.0 ab	61.3 bc	93.0 b	71.0 c	0.69 a	0.26 a	0.17 a
R1	30 + 15	31.0 b	31.8 a	25.5 ab	80.3 a	120.5 a	141.8 ab	0.58 a	0.21 a	0.04 c
R3	30 + 15	34.5 a	35.3 a	27.8 ab	72.8 ab	114.3 ab	132.ab	0.60 a	0.22 a	0.08 bc
R5	30 + 15	33.8 a	34.5 a	28.3 ab	74.5 a	123.8 a	90.8 bc	0.50 a	0.25 a	0.14 ab
R3 + R5	60 + 30	35.0 a	36.8 a	29.3 a	59.8 c	90.3 b	116.3 abc	0.59 a	0.20 a	0.10 abc
R1 + R3 + R5	90 + 30	29.8 a	31.8 a	24.3 b	69.5 abc	107.5 ab	169.8 a	0.52 a	0.23 a	0.04 c
LSD		2.32	5.06	4.79	12.3	24.6	55	0.33	0.07	0.08
			NS	NS				NS	NS	
Sufficiency Range[3]			21 - 60			25 - 200			0.21 – 4.00	

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

Irrigation Treatment	Total N + S	Tissue[1]								
		Copper			Iron			Zinc		
		7/27/2015	8/12/2015	9/2/2015	7/27/2015	8/12/2015	9/2/2015	7/27/2015	8/12/2015	9/2/2015
	lbs/A	ppm			ppm			ppm		
No fertigation	0	9.4 a[2]	11.63 a	9.1 a	72.8 a	93.0 ab	75.8 a	60.8 a	124.3 a	68.0 b
R1	30 + 15	10.3 a	11.95 a	9.2 a	76.8 a	95.8 a	77.0 a	76.5 a	172.5 a	116.3 ab
R3	30 + 15	9.3 a	11.00 a	9.3 a	71.3 a	90.0 b	79.8 a	64.3 a	145.5 a	96.0 ab
R5	30 + 15	9.1 a	10.60 a	9.7 a	73.5 a	89.0 b	76.5 a	67.3 a	151.8 a	84.0 ab
R3 + R5	60 + 30	9.0 a	11.10 a	9.3 a	72.5 a	90.3 b	76.4 a	60.5 a	153.0 a	98.0 ab
R1 + R3 + R5	90 + 30	10.3 a	11.93 a	9.5 a	75.5 a	96.3 a	79.3 a	79.5 a	147.8 a	145.8 a
LSD		2	1.59	1.37	11.1	4.77	5.07	21.5	60.1	52.4
		NS	NS	NS	NS		NS	NS	NS	NS
Sufficiency Range[3]			6 - 20			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 11. Double Crop Soybean Study - Fertigation treatment effect on leaf tissue nitrogen, sulfur, and phosphorus on multiple dates.

		Tissue[1]								
Irrigation	Total	Nitrogen			Sulfur			Phosphorus		
Treatment	N + S	8/27/2015	9/10/2015	10/7/2015	8/27/2015	9/10/2015	10/7/2015	8/27/2015	9/10/2015	10/7/2015
	lbs/A	%			%			%		
No fertigation	0	6.42 c[2]	5.70 b	4.14 a	0.30 c	0.30 c	0.25 a	0.46 a	0.35 a	0.23 a
R1	30 + 15	7.04 a	5.77 ab	3.87 a	0.33 a	0.32 abc	0.24 a	0.49 a	0.36 a	0.23 a
R3	30 + 15	6.58 bc	5.92 a	3.99 a	0.31 abc	0.33 a	0.24 a	0.49 a	0.36 a	0.24 a
R5	30 + 15	6.58 bc	5.76 ab	4.12 a	0.31 bc	0.31 bc	0.25 a	0.49 a	0.36 a	0.25 a
R3 + R5	60 + 30	6.35 c	5.81 ab	4.00 a	0.30 c	0.33 a	0.25 a	0.46 a	0.34 a	0.23 a
R1 + R3 + R5	90 + 30	6.90 ab	5.75 b	3.86 a	0.33 ab	0.32 abc	0.24 a	0.46 a	0.35 a	0.23 a
LSD		0.39	0.17	0.35	0.02	0.019	0.013	0.06	0.03	0.04
			NS	NS	NS		NS	NS	NS	NS
Sufficiency Range[3]			4.26 - 5.50			0.18 – 0.30			0.26 - 0.50	

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

		Tissue[1]								
Irrigation	Total	Potassium			Magnesium			Calcium		
Treatment	N + S	8/27/2015	9/10/2015	10/7/2015	8/27/2015	9/10/2015	10/7/2015	8/27/2015	9/10/2015	10/7/2015
	lbs/A	%			%			%		
No fertigation	0	2.23 ab[2]	2.02 a	1.75 a	0.34 ab	0.24 a	0.16 a	0.77 a	0.76 a	1.09 b
R1	30 + 15	2.21 ab	1.91 a	1.57 ab	0.34 ab	0.25 a	0.17 a	0.79 a	0.74 a	1.34 ab
R3	30 + 15	2.32 a	2.04 a	1.62 ab	0.34 ab	0.24 a	0.17 a	0.79 a	0.76 a	1.34 ab
R5	30 + 15	2.26 ab	2.03 a	1.59 ab	0.35 a	0.24 a	0.18 a	0.78 a	0.76 a	1.39 ab
R3 + R5	60 + 30	2.17 ab	1.98 a	1.57 ab	0.34 ab	0.24 a	0.18 a	0.77 a	0.79 a	1.44 a
R1 + R3 + R5	90 + 30	2.25 ab	1.95 a	1.48 b	0.33 b	0.24 a	0.17 a	0.80 a	0.80 a	1.55 a
LSD		0.14	0.16	0.25	0.02	0.01	0.04	0.05	0.08	0.31
		NS	NS	NS	NS	NS	NS	NS	NS	NS
Sufficiency Range[3]			2.00 – 2.80			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 13. Double Crop Soybean Study - Fertigation treatment effect on leaf tissue boron, manganese, and molybdenum on multiple dates.

		Tissue[1]								
Irrigation	Total	Boron			Manganese			Molybdenum		
Treatment	N + S	8/27/2015	9/10/2015	10/7/2015	8/27/2015	9/10/2015	10/7/2015	8/27/2015	9/10/2015	10/7/2015
	lbs/A	ppm			ppm			ppm		
No fertigation	0	35.5 ab[2]	30.8 ab	28 ab	107.0 a	103.0 c	120.0 c	0.07 a	0.11 a	0.06 a
R1	30 + 15	34.3 ab	27.5 b	26.5 b	109.8 a	114.5 bc	166.3 bc	0.16 a	0.08 ab	0.08 a
R3	30 + 15	36.3 a	29.8 ab	28.5 ab	100.3 a	101.8 c	148.8 c	0.08 a	0.07 ab	0.03 a
R5	30 + 15	35.5 ab	33.3 a	29.3 a	99.0 a	104.0 c	140.8 c	0.08 a	0.06 ab	0.02 a
R3 + R5	60 + 30	34.0 ab	28.3 b	27.5 ab	115.0 a	127.8 ab	199.8 b	0.04 a	0.09 ab	0.05 a
R1 + R3 + R5	90 + 30	35.0 ab	27.5 b	26.5 b	110.0 a	138.8 a	301.5 a	0.14 a	0.40 b	0.05 a
LSD		2.21	4.8	2.3	20.95	15.31	49.77	0.12	0.06	0.09
		NS	NS	NS	NS			NS	NS	NS
Sufficiency Range[3]		21 - 60			25 - 200			0.21 – 4.00		

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

		Tissue[1]								
Irrigation	Total	Copper			Iron			Zinc		
Treatment	N + S	8/27/2015	9/10/2015	10/7/2015	8/27/2015	9/10/2015	10/7/2015	8/27/2015	9/10/2015	10/7/2015
	lbs/A	ppm			ppm			ppm		
No fertigation	0	8.23 a[2]	9.78 a	8.68 ab	78.3 a	84.8 a	75.0 ab	67.5 a	70.5 a	64.5 b
R1	30 + 15	8.28 a	9.98 a	8.53 ab	79.8 a	80.5 ab	72.0 ab	73.5 a	77.8 a	86.8 b
R3	30 + 15	8.53 a	9.48 a	8.08 b	79.3 a	83.3 ab	72.3 ab	66.3 a	69.8 a	73.5 b
R5	30 + 15	8.48 a	10.13 a	8.73 a	77.8 a	82.8 ab	80.3 a	63.3 a	76.8 a	70.3 b
R3 + R5	60 + 30	8.13 a	9.78 a	8.10 ab	79.5 a	83.3 ab	75.0 ab	67.8 a	81.5 a	85.0 b
R1 + R3 + R5	90 + 30	8.50 a	9.90 a	8.60 ab	81.3 a	79.0 b	70.3 b	70.3 a	86.0 a	128.5 a
LSD		0.9	1.12	0.63	5.4	5.3	8.6	14.3	20.3	34.4
		NS	NS	NS	NS	NS	NS	NS	NS	
Sufficiency Range[3]		6 - 20			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.