**Final Report to Delaware Soybean Board**

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**Delaware Soybean Board (susanne@hammondmedia.com)**

**Effect of Fertigation on Irrigated Full Season Soybeans**

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**Objectives**

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

**THREE YEAR AVERAGE YIELD TREND**

In research conducted at the University of Delaware Warrington Irrigation Research Farm in 2015, 2016, and 2017 trends in soybean response to nitrogen (N) and sulfur (S) fertigation are developing. There was a significant yield response in all three 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 (*Table 3*). 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).

**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) 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**

A study was conducted in 2017 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 fertigation treatments. All treatments were replicated four times.

1. No fertigation (control)
2. R1 fertigation – Nitrogen (30 lbs/A) + Sulfur (15 lbs/A)
3. R1 + R3 fertigation – Nitrogen applied 2 times (total of 60 lbs/A) + Sulfur applied 2 times (total of 30 lbs/A)
4. 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 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 | 5/15/17 |  |
| Variety | Asgrow 4135 |  |
| Target Seeding Rate/A | 155,000 |  |
|  |  |  |
| *Pesticide Applications* |  |  |
| Canopy 4 oz/A | 5/15/17 |  |
| Glyphosate 30 oz/A + Reflex 1.5 pt/A | 6/27/17 |  |
| Priaxor 6 oz/A + Hero 10.3 oz/A | 8/3/17 |  |
|  |  |  |
| *Harvest Date* | 11/3/17 |  |
|  |  |  |

*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 | 6/18/17 |  |
| V4 | 4-trifoliolate | 6/25/17 |  |
| V6 | 6-trifoliolate | 7/8/17 |  |
| R1 | Begin Flower | 7/13/17 |  |
| R2 | Full Flower | 7/20/17 |  |
| R3 | Begin Pod | 8/1/17 |  |
| R4 | Full Pod | 8/7/17 |  |
| R5 | Begin Seed | 8/15/17 |  |
| R6 | Full Seed | 8/31/17 |  |
| R7 | Begin Maturity | 9/22/17 |  |
| R8 | Full Maturity | 10/10/17 |  |

**RESULTS**

In 2017, the Delaware Soybean Board funded a study to evaluate nitrogen and sulfur fertigation on irrigated full season soybeans. Treatments were planned to be the same in 2017 as those conducted in 2015 and 2016, however significant deer damage early in the season resulted in lost plot area and treatment number was reduced to 4.

Nitrogen (N) + sulfur (S) was applied at R1, R1 + R3, 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 treatments, whereas the R1 + R3 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.

Yields ranged from 72 to 79 bu/A. The largest yield response was from the R1 + R3 treatment where soybeans yielded 7 bu/A greater than the no fertigation treatment (*Table 3*). At maturity, soybean heights ranged from 38 in. to 39 in. (*Table 4*).

There were some differences and trends observed in nutrient tissue content. Tissue samples were collected before fertigation treatments were initiated at R1 and 1 week after each fertigation timing on 7/20, 8/9, and 8/22. On the 7/9 sample date before fertigation, tissue nitrogen levels ranged from 5.82 to 5.92 ppm (*Table 5*). The largest increase in tissue N concentration was observed when N was applied at R1 and R3. N + S applied at R3 resulted in the greatest tissue N concentration on the 8/22 sample date.

Tissue sulfur levels were within the sufficient range or above throughout the season in all treatments (*Table 5*). Sulfur tissue levels were highest on the 8/22 sample date when treatments included N + S applied at R3.

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 8/22 sample date, potassium was below the sufficiency range (*Table 6*). Magnesium was below the sufficiency range on the last 2 sample dates (*Table 6*). Tissue molybdenum levels were found to be well below the sufficiency range on the last sample date (*Table* 8). These are interesting results that we would like to explore in 2018.

***Table 3. Full Season Study*** – Fertigation treatment effect on soybean yield.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Fertigation Treatment1 | Total  N + S | Yield | | | |
| 2 yr Avg2 | 2015 | 2016 | 2017 |
|  | lbs/A | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ bu/A \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | |
|  |  |  |  |  |  |
| No fertigation | 0 | 73.1 c3 | 77 c | 70 b | 72 b | |
| R1 | 30 + 15 | 81.7 a | 85 a | 78 a | 73 b | |
| R3 | 30 + 15 | 76.4 bc | 78 bc | 74 ab | -- | |
| R5 | 30 + 15 | 75.9 bc | 78 bc | 74 ab | -- | |
| R1 + R3 | 60 + 30 | -- | -- | -- | 79 a | |
| R3 + R5 | 60 + 30 | 78.3 ab | 82 ab | 75 ab | -- | |
| R1 + R3 + R5 | 90 + 45 | 77.3 b | 78 bc | 77 a | 75 ab | |
|  |  |  | 5 | NS4 |  |

1Fertigation at each timing included 30 lbs N per acre and 15 lbs S per acre.

2Yield data combined from 2015 and 2016.

3Treatment means followed by the same letter are not significantly different.

4Treatments were separated using Fisher’s Protected LSD test. NS=not significant.

***Table 4. Full Season Soybean Study*** - Fertigation treatment effect on soybean plant height.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Fertigation Treatment1 | Total  N + S | Plant Height | | | |
| 7/26/17 | 8/11/17 | 11/3/17 |
|  | lbs/A | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ in. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | |
| No fertigation | 0 | 26.1 a2 | 38.3 a | 39.8 a |
| R1 | 30 + 15 | 26.7 a | 39.8 a | 39.8 a |
| R1 + R3 | 60 + 3 | 26.8 a | 39.7 a | 39.8 a |
| R1 + R3 + R5 | 90 + 45 | 26.8 a | 39.3 a | 38.1 a |
|  |  | NS3 | NS | NS |

1Fertigation at each timing included 30 lbs N per acre and 15 lbs S per acre.

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

3Treatments were separated using Fisher’s Protected LSD test. NS=not significant.

***Table 5. Full Season Soybean Study*** - Fertigation treatment effect on leaf tissue nitrogen, sulfur, and phosphorus on multiple dates.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Tissue1 | | | | | | | | | | | |
| Fertigation Treatment | Total  N + S | Nitrogen | | | | Sulfur | | | | Phosphorus | | | |
| 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 | 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 | 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 |
|  | lbs/A | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | |
| No fertigation | 0 | 5.89 a2 | 6.12 a | 5.30 b | 5.18 ab | 0.31 a | 0.36 a | 0.32 bc | 0.30 b | 0.56 a | 0.58 a | 0.42 a | 0.36 ab |
| R1 | 30 + 15 | 5.88 a | 6.37 a | 5.43 b | 5.11 b | 0.32 a | 0.37 a | 0.30 c | 0.30 b | 0.57 a | 0.57 a | 0.43 a | 0.38 a |
| R1 + R3 | 60 + 30 | 5.92 a | 6.40 a | 5.94 a | 5.43 ab | 0.32 a | 0.38 a | 0.37 ab | 0.33 a | 0.58 a | 0.57 a | 0.43 a | 0.33 b |
| R1 + R3 + R5 | 90 + 45 | 5.82 a | 6.39 a | 5.89 a | 5.56 a | 0.31 a | 0.39 a | 0.39 a | 0.35 a | 0.56 a | 0.52 a | 0.42 a | 0.33 b |
|  |  | NS | NS |  | NS | NS | NS |  |  | NS | NS | NS |  |
| Sufficiency Range3 | | 4.26 - 5.50 | | | | 0.18 – 0.30 | | | | 0.26 - 0.50 | | | |

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

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Tissue1 | | | | | | | | | | | |
| Fertigation Treatment | Total  N + S | Potassium | | | | Magnesium | | | | Calcium | | | |
| 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 | 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 | 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 |
|  | lbs/A | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | |
| No fertigation | 0 | 2.69 a2 | 2.65 a | 2.15 b | 1.93 a | 0.39 a | 0.46 a | 0.26 a | 0.17 b | 0.74 a | 1.50 a | 0.77 a | 0.88 a |
| R1 | 30 + 15 | 2.80 a | 2.63 a | 2.17 ab | 1.92 a | 0.39 a | 0.42 a | 0.26 a | 0.20 a | 0.75 a | 0.98 a | 0.75 a | 1.03 a |
| R1 + R3 | 60 + 30 | 2.73 a | 2.68 a | 2.30 a | 1.93 a | 0.40 a | 0.43 a | 0.27 a | 0.17 ab | 0.73 a | 0.95 a | 1.03 a | 0.97 a |
| R1 + R3 + R5 | 90 + 45 | 2.66 a | 2.66 a | 2.17 ab | 1.90 a | 0.40 a | 0.41 a | 0.25 a | 0.18 ab | 0.75 a | 1.01 a | 0.79 a | 1.06 a |
|  |  | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Sufficiency Range3 | | 2.00 – 2.80 | | | | 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 7. Full Season Soybean Study*** - Fertigation treatment effect on leaf tissue boron, manganese, and molybdenum on multiple dates.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Tissue1 | | | | | | | | | | | |
| Fertigation Treatment | Total  N + S | Boron | | | | Manganese | | | | Molybdenum | | | |
| 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 | 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 | 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 |
|  | lbs/A | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | |
| No fertigation | 0 | 34.5 a2 | 33.5 a | 27.3 a | 22.3 a | 79 a | 113 a | 112 ab | 159 b | 0.52 a | 0.57 a | 0.55 a | 0.11 a |
| R1 | 30 + 15 | 34.8 a | 31.8 a | 28.0 a | 23.8 a | 72 a | 96 a | 82 b | 122 b | 0.66 a | 0.71 a | 0.44 a | 0.10 a |
| R1 + R3 | 60 + 30 | 33.8 a | 33.3 a | 29.3 a | 24.0 a | 70 a | 91 a | 101 ab | 166 b | 0.59 a | 0.50 a | 0.48 a | 0.01 a |
| R1 + R3 + R5 | 90 + 45 | 35.3 a | 33.0 a | 25.3 a | 22.3 a | 88 a | 126 a | 135 a | 245 a | 0.53 a | 0.40 a | 0.35 a | 0.01 a |
|  |  | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Sufficiency Range3 | | 21 - 60 | | | | 25 - 200 | | | | 0.21 – 4.00 | | | |

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

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | Tissue1 | | | | | | | | | | | |
| Fertigation Treatment | Total  N + S | Copper | | | | Iron | | | | Zinc | | | |
| 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 | 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 | 7/10/17 | 7/20/17 | 8/9/17 | 8/22/17 |
|  | lbs/A | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | |
| No fertigation | 0 | 11.4 a2 | 13.1 ab | 10.1 a | 11.4 a | 94 a | 112 a | 93 b | 100 a | 119 a | 157 a | 124 ab | 202 ab |
| R1 | 30 + 15 | 11.2 a | 11.7 b | 9.3 a | 9.9 b | 100 a | 102 a | 101 ab | 92 a | 112 a | 138 a | 101 b | 163 ab |
| R1 + R3 | 60 + 30 | 11.0 a | 11.6 b | 9.4 a | 9.5 b | 90 a | 101 a | 108 ab | 92 a | 94 b | 123 a | 102 b | 155 b |
| R1 + R3 + R5 | 90 + 45 | 12.5 a | 13.9 a | 8.7 a | 9.8 b | 96 a | 112 a | 126 a | 99 a | 122 a | 178 a | 141 a | 213 a |
|  |  | NS | NS | NS |  | NS | NS | NS | NS | NS | NS | NS | NS |
| Sufficiency Range3 | | 6 - 20 | | | | 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.