**Final Report to Delaware Soybean Board**

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

**Evaluating the Response of Full Season Soybeans to Various Soil Moisture Levels**

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**OBJECTIVES**

1. Evaluate the effects of various soil moisture levels on growth and yield of full season soybeans.
2. Determine the optimal irrigation management strategy for full season soybeans to maximize yield and profitability.

**FIVE YEAR AVERAGE YIELD TREND**

Soybean irrigation research was conducted at the University of Delaware Warrington Irrigation Research Farm from 2012 to 2017. Over these years, there were only slight differences in yield between irrigation strategies in full season (*Table 1*) soybeans. Yield with strategies of limited irrigation (>30% soil moisture) to later growth stages were comparable to strategies that provided full irrigation (>50% soil moisture) all season (*Table 1*).

In 2015, 2016, and 2017 studies, new treatments were included to determine if irrigation could be completely delayed until later growth stages (R3 and R5). Averaged over these three years in the full season study, delaying irrigation to R3 provided similar yield to all other irrigated treatments. There was a slight decrease in yield when irrigation was delayed to R5, however yield was significantly higher than the no irrigation treatment (*Table 1*).

***Table 1a.* Full Season Study** – Irrigation treatment effect on soybean yield averaged over 3 years and in 2012, 2013, 2014, 2015, 2016, and 2017.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Yield | | | | | | | |
| Irrigation Treatment1 | 3 yr Avg2 | 3 yr Avg3 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|  | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ bu/A \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | | | | |
| No Irr. | 40 c4 | 65 e | 54 c | 69 abc | 73 b | 25 c | 55 c | 68.7 a |
| No Irr. to R1 then >50% | 73 ab | 70 bc | 63 b | 71 ab | 76 ab | 74 ab | 72 ab | 69.8 a |
| No Irr. to R3 then >50% | 73 ab | -- | -- | -- | -- | 80 a | 66 b | 70.9 a |
| No Irr. to R5 then >50% | 68 b | -- | -- | -- | -- | 68 b | 68 ab | 69.4 a |
| Limited Irr. to R1 then >50% | 75 ab | 70 abc | 67 ab | 69 abc | 75 ab | 76 ab | 73 ab | 69.4 a |
| Limited Irr. to R3 then >50% | 70 ab | 72 a | 66 ab | 73 a | 77 a | 73 ab | 67 ab | 68.1 a |
| Limited Irr. to R5 then >50% | 73 ab | 72 ab | 70 a | 71 ab | 73 b | 72 b | 73 ab | 69.7 a |
| Limited Irr. to R1 then >50% to R3 then >70% | -- | 70 bc | 63 b | 71 ab | 75 ab | -- | -- | -- |
| Full Season Irr. >30% | 71 ab | -- | -- | -- | -- | 77 ab | 65 b | 70.2 a |
| Full Season Irr. >50% | 75 a | 67 de | 63 b | 65 d | 74 ab | 75 ab | 75 a | 72.8 a |
| KanSched2 (ET) >50% | -- | 68 cd | 65 ab | 66 cd | 73 b | -- | -- | -- |

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

2Data combined from 2015, 2016, and 2017.

3Data combined from 2012, 2013, and 2014.

4Treatment means followed by the same letter are not significantly different.

***Table 1c.* Full Season Study** – Irrigation treatment effect on amount of irrigation applied averaged over 3 years and in 2012, 2013, 2014, 2015, 2016, and 2017.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Irrigation Applied | | | | | | | |
| Irrigation Treatment1 | 3 yr Avg2 | 3 yr avg3 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|  | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ inches \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | | | | | | |
| No Irr. | 0.0 d4 | 0.0 e | 0.0 d | 0.0 d | 0.0 e | 0.0 e | 0.0 c | 0.0 e |
| No Irr. to R1 then >50% | 6.5 ab | 5.0 c | 6.8 abc | 5.4 abc | 2.9 cd | 8.8 ab | 7.2 a | 3.4 ab |
| No Irr. to R3 then >50% | 5.6 b | -- | -- | -- | -- | 8.0 ab | 7.3 a | 1.6 d |
| No Irr. to R5 then >50% | 4.4 c | -- | -- | -- | -- | 5.6 cd | 6.1 ab | 1.5 d |
| Limited Irr. to R1 then >50% | 6.7 a | 5.7 c | 8.1 abc | 5.5 abc | 3.6 c | 9.6 a | 6.1 ab | 4.3 a |
| Limited Irr. to R3 then >50% | 6.0 ab | 4.9 cd | 6.5 bc | 4.3 c | 3.9 c | 7.3 bcd | 7.8 a | 2.8 bc |
| Limited Irr. to R5 then >50% | 5.7 b | 4.0 d | 5.3 c | 4.8 bc | 1.9 d | 7.5 bc | 6.9 ab | 2.5 bcd |
| Limited Irr. to R1 then >50% to R3 then >70% | -- | 7.4 ab | 9.6 a | 7.0 a | 5.5 b | -- | -- | -- |
| Full Season Irr. >30% | 4.1 c | -- | -- | -- | -- | 5.3 d | 4.9 b | 2.2 cd |
| Full Season Irr. >50% | 6.7 a | 6.8 b | 8.3 ab | 6.3 ab | 5.8 b | 8.4 ab | 7.8 a | 4.0 a |
| KanSched2 (ET) >50% | -- | 8.0 a | 9.0 ab | 5.9 abc | 9.0 a | -- | -- | -- |

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

2Data combined from 2015, 2016, and 2017.

3Data combined from 2012, 2013, and 2014.

4Treatment means followed by the same letter are not significantly different.

**INDIVIDUAL SUMMARY OF 2012, 2013, 2014, 2015, 2016, and 2017 TRIALS**

**2017 (6th year to trial).**

In 2017, rainfall was below average in June (2.08”), above average in July (6.88”) and August (5.30”), and below average in September (2.25”).

Soybeans were initially planted on May 12, however the entire study had to be destroyed and replanted due to significant deer damage. Soybeans were replanted on June 15. The amount of water applied based on the irrigation strategy ranged from 1.5” to 4.0”. The above average rainfall in July and August attributed to an excellent non-irrigated soybean yield and no significant difference in yield between any treatment. Yields ranged from 68.1 to 72.8 bu/A.

**2016 (5th year of trial).**

In 2016, rainfall was below average in June (2.99”), July (3.53”), and August (2.12”). Rainfall total from August 1 to September 15 was 2.98”, which averaged 0.06” per day over that time period.

In the full season soybean study, soybeans were planted on June 3. The amount of water applied based on the irrigation strategy ranged from 4.9” to 7.8”. Average yield in plots that received irrigation ranged from 65 to 75 bu/A compared to 55 bu/A in plots that received no irrigation. The irrigation strategy that produced the highest yield (75 bu/A) was the full season irrigation treatment that maintained soil moisture >50%, but was not statistically different from all limited irrigation treatments to later growth stages and no irrigation to R1 and R5. There was a significant difference between the full season >50% irrigation treatment and the no irrigation to R3 and the full season irrigation >30%.

**2015 (4th year of trial).**

In 2015, rainfall was above average in June (6.00”), average in September (4.20”), and below average in July (2.50”) and August (2.25”). Rainfall total from July 1 to September 9 was 4.75”, which averaged 0.07” per day over that time period. Rainfall total from August 12 to September 9 was only 0.21”, which averaged 0.01” per day over that time period.

In the full season soybean study, soybeans were planted on May 27. The amount of water applied based on the irrigation strategy ranged from 5.3” to 9.6”. Average yield in plots that received irrigation ranged from 68 to 80 bu/A compared to 25 bu/A in plots that received no irrigation. The irrigation strategy that produced the greatest yield (80 bu/A) was when no irrigation was applied until R3 then applied to maintain available soil moisture >50% until maturity. However, yield attained by this irrigation strategy was only statistically different from the no irrigation treatment (25 bu/A) and strategies that applied no irrigation until R5 then >50% available moisture to maturity (68 bu/A) and limited irrigation to R5 then >50% soil moisture to maturity (72 bu/A).

**2014 (3rd year of trial).** In 2014, rainfall was above average in July (6.76”) and August (5.76”), but below average in June (2.05”) and September (3.99”). In June, July, and August, rainfall in the last 2 weeks of each month was less than 0.88 in. There was a 4 week period from 8/16 to 9/15, where Harbeson received only 1.56” of rainfall.

In the full season soybean study, soybeans were planted on May 20. Average yield in plots that received irrigation ranged from 73 to 77 bu/A compared to 73 bu/A in plots that received no irrigation. There was no significant difference between any irrigation treatments this year. The amount of water applied based on the irrigation strategy ranged from 1.9 in. to 9.0 in. Soybeans planted in 7.5 in., 15 in., and 30 in. row widths yielded similarly to each irrigation strategy, but there was a slight yield difference between row widths. Average soybean yield was 76 bu/A in 7.5 in. rows, 74 bu/A in 15 in. rows, and 74 bu/A in 30 in. rows.

**2013 (2nd year of trial).** In 2013, rainfall totals in June (10.4”), July (6.9”), August (6.5”) and October (6.1”) were above average, but rainfall was well below average in September (0.7”).

In the full season soybean study, soybeans were planted on May 19. Average yield in plots that received irrigation ranged from 65 to 73 bu/A compared to 69 bu/A in plots that received no irrigation. The amount of water applied based on the irrigation strategy ranged from 4.3” to 7.0”. The irrigation strategy that produced the greatest yield (73 bu/A) was when irrigation was applied at a limited amount (>30% available moisture) until the R3 growth stage and then applied to maintain available soil moisture >50% until maturity and was also the irrigation strategy with the least amount of water applied (4.3”). However, yield attained by this irrigation strategy was not statistically different from the no irrigation treatment and strategies that applied no irrigation until R1 and limited irrigation to R1 and R5, where yields ranged from 69 to 71 bu/A. The two irrigation strategies, full season irrigation (65 bu/A) and an ET based program (66 bu/A), that maintained soil moisture >50% all season were the only two strategies that produced less yield than the no irrigation treatment. Soybeans planted in 7.5”, 15”, and 30” row widths yielded similarly to each irrigation strategy, but there was an overall yield difference between row widths. Average soybean yield was 72.8 bu/A in 7.5” rows, 68.6 bu/A in 15” rows, and 66.4 bu/A in 30” rows.

**2012 (1st year of trial).** In 2012, rainfall totals in May (0.5”), June (2.5”), July (2.5”), and September (2.8”) were below average, but rainfall was well above average in August (10.6”).

In the full season study, average yield in plots that received irrigation ranged from 63 to 70 bu/A compared to 54 bu/A in plots that received no irrigation. The amount of water applied based on the irrigation strategy ranged from 5.3” to 9.6”. The irrigation strategy that produced the greatest yield (70 bu/A) was when irrigation was applied at a reduced amount (>30% available soil moisture) until the R5 growth stage and then >50% available soil moisture until maturity. This irrigation strategy also required the least amount of water applied (5.3”). There was no yield advantage in irrigating to maintain >50% available soil moisture until Mid-August this year. Soybeans in all row widths responded similarly to each irrigation strategy, but there was an overall yield difference between row widths. Average soybean yield was 67 bu/A in 15” rows, 64 bu/A in 7” rows, and 61 bu/A in 30” rows.

**MATERIALS AND METHODS**

A study was conducted in 2017 to determine the response of full season soybeans to various soil moisture levels. Both studies were 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 irrigation treatments. All treatments were replicated five times.

***Irrigation Treatments:***

1. No irrigation.
2. No irrigation until flowering (R1) then >50% soil moisture.
3. No irrigation until pod development (R3) then >50% moisture.
4. No irrigation until seed development (R5) then >50% soil moisture.
5. Limited irrigation (>30% soil moisture) until flowering (R1 then >50% soil moisture.
6. Limited irrigation (>30% soil moisture) until pod development (R3) then >50% moisture.
7. Limited irrigation (>30% soil moisture) until seed development (R5) then >50% soil moisture.
8. Full season irrigation (>30% soil moisture throughout the season).
9. Full season irrigation (>50% soil moisture throughout the season).

**Field Operations**. The entire study area was treated identically for all production inputs except irrigation. Fertilizer was applied based on the University of Delaware recommendations for soybean. Soybeans were grown under conventional tillage practices. Soybeans were planted in 15 in. rows with a Monosem planter. Planting date, soybean variety, seeding rate, pesticide applications, and harvest date are presented in *Table 2*.

***Table 2.*** Planting date, variety, seeding rate, pesticide applications, and harvest date for the

full season and double crop soybean studies.

|  |  |
| --- | --- |
| **Operation** | **Full Season Study** |
| Planting Date | 6/16/17 |
| Variety | CZ 4222LL |
| Target Seeding Rate/A | 165,000 |
|  |  |
| *Pesticide Applications* |  |
| Canopy 4 oz/A | 5/15/17 |
| Liberty 32 oz/A + Reflex 1.5 pt/A | 7/16/17 |
| Priaxor 6 oz/A + Hero 10.3 oz/A | 8/15/17 |
|  |  |
| *Harvest Date* | 11/4/17 |

*Soil Moisture Monitoring to Trigger Irrigation Treatments.* Soil moisture was monitored in each plot using Watermark soil moisture sensors placed at 4 in., 10 in., and 16 in. below the soil line. A Watermark 950T transmitter was used at all moisture monitoring locations to wirelessly transmit data to a Watermark 950R data logging receiver. Moisture data was viewed and interpreted daily to determine if any treatments required irrigation. Irrigation was applied to plots when soil moisture at the 4 in. or 10 in. depth reached the specific irrigation treatment requirement.

**Data Collected.** In-season growth stages (*Table 3*) and plant heights were recorded on multiple dates. Soybean yield, moisture, and test weight were determined by harvesting the middle rows of each plot 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 the Least Significant Difference (LSD) test at the 5% probability level. Total water applied for each irrigation treatment was determined and the economic implications of each irrigation management strategy were calculated based on soybean yield, soybean selling price, and irrigation energy costs.

***Table 3.*** Soybean growth stages by date in 2017.

|  |  |  |
| --- | --- | --- |
| **Growth Stage** | **Growth Stage Description** | **Date** |
| V2 | 2-trifoliolate | 7/2/17 |
| V4 | 4-trifoliolate | 7/12/17 |
| V6 | 6-trifoliolate | 7/18/17 |
| R1 | Begin Flower | 7/21/17 |
| R2 | Full Flower | 7/26/17 |
| R3 | Begin Pod | 8/11/17 |
| R4 | Full Pod | 8/15/17 |
| R5 | Begin Seed | 8/23/17 |
| R6 | Full Seed | 9/10/17 |
| R7 | Begin Maturity | 9/25/17 |
| R8 | Full Maturity | 10/8/17 |

***Figure 1*.** Bi-weekly rainfall total at the study site in Harbeson, DE in 2017.

***Table 4.*** Total monthly rainfall, average daily rainfall, and time periods with low rainfall.

|  |  |  |  |
| --- | --- | --- | --- |
| **Time Period** | **Rainfall Total** |  | **Average Daily Rainfall** |
|  | \_\_\_\_\_\_ Inches \_\_\_\_\_\_\_ |  | \_\_\_\_\_\_ Inches \_\_\_\_\_\_\_ |
| June | 2.08 |  | 0.07 |
| July | 6.88 |  | 0.22 |
| August | 5.30 |  | 0.17 |
| September | 2.25 |  | 0.08 |
| October 1 to 15 | 0.84 |  | 0.06 |

**RESULTS AND DISCUSSION**

**In-Season Rainfall.** *Figure 1* shows the bi-weekly rainfall at the study site in Harbeson, DE in 2017. Rainfall was below average in June (2.08”), above average in July (6.88”) and August (5.30”), and below average in September (2.25”) (*Figure 1 and Table 4*).

**Irrigation Applied.** Bi-weekly and total irrigation applied for each treatment are shown in *Figure 2.*  The amount of water applied based on the irrigation strategy ranged from 1.5” to 4.0” (*Table 6)*.

**Soybean Growth.**

***Full Season Study*** *–* Soybean heights were measured on 7/26, 8/11, and 11/4 (*Table 5*).

*Plant Height by Irrigation Treatment.* Heights ranged from 34.7 in. to 38.7 in. (*Table 5*). There were no significant difference between treatments on soybean height probably due to the above average rainfall in July and August.

**Yield.**

***Full Season Study*** – Soybeans were harvested on 11/4.

*Yield by Irrigation Treatment.* The irrigation strategy that produced the highest yield (72.8 bu/A) was the full season irrigation treatment that maintained soil moisture >50%, but was not statistically different from all other irrigation treatment and the no irrigation treatment (*Figure 2; Table 6*). It seems the above average rainfall in July and August was adequate to achieve maximum yields, even under no irrigation. It is interesting to note that the below average rainfall in September did not affect yields.

**Economics.**

***Full Season Study*** – The top 3 most profitable treatments based on yield and total irrigation applied were 1) Full season irrigation >50%, 2) no irrigation until R3 then >50% moisture, and 3) full season irrigation >30% (*Table* 6).

***Figure 2. Full Season Study –*** Soybean yield and total irrigation applied bi-weekly by treatment. Each color represents the total amount of irrigation applied during the date range listed. The top of the bar column represents the total irrigation applied for the season.

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

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

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

|  |  |  |  |
| --- | --- | --- | --- |
|  | Plant Height | | |
| Irrigation Treatment1 | 7/26/17 | 8/11/17 | 11/4/17 |
|  | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ in. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | |
| No Irr. | 12.1 bc2 | 24.1 ab | 35.4 ab |
| No Irr. to R1/R2 then >50% | 12.4 abc | 24.5 ab | 36.6 ab |
| No Irr. to R3/R4 then >50% | 12.1 abc | 25.1 ab | 37.4 ab |
| No Irr. to R5/R6 then >50% | 12.3 abc | 25.1 ab | 36.2 ab |
| Limited Irr. to R1/R2 then >50% | 12.7 ab | 23.4 b | 35.7 ab |
| Limited Irr. to R3/R4 then >50% | 11.4 c | 23.6 ab | 34.7 b |
| Limited Irr. to R5/R6 then >50% | 12.1 abc | 23.5 ab | 35.3 ab |
| Full Season Irr. >30% | 12.7 ab | 24.7 ab | 36.5 ab |
| Full Season Irr. >50% | 13.4 a | 25.5 a | 38.7 a |
|  | NS3 | NS | NS |

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

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

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

***Table 6. Full Season Soybean Study*** - Irrigation treatment effect on soybean lodging, moisture, yield, total irrigation applied, irrigation energy cost per acre, and gross income at multiple soybean prices.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Total Irrigation Applied | Irrigation Energy Cost2 | Gross Income minus Irrigation Energy Cost4 | | |
| Irrigation Treatment1 | Moisture | Yield | $6.00/bu3 | $8.00/bu | $10.00/bu |
|  | \_\_\_\_ % \_\_\_\_ | \_\_ bu/A \_\_ | \_\_\_ in. \_\_\_ | \_ $/Acre \_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ $ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | | |
| No Irr. | 15.0 ab5 | 68.7 a | 0.0 e | 0.00 | 412.20 | 549.60 | 687.00 |
| No Irr. to R1 then >50% | 15.0 ab | 69.8 a | 3.4 ab | 17.00 | 401.80 | 541.40 | 681.00 |
| No Irr. to R3 then >50% | 15.1 a | 70.9 a | 1.6 d | 8.00 | 417.40 | 559.20 | 701.00 |
| No Irr. to R5 then >50% | 15.1 a | 69.4 a | 1.5 d | 7.50 | 408.90 | 547.70 | 686.50 |
| Limited Irr. to R1 then >50% | 14.9 ab | 69.4 a | 4.3 a | 21.50 | 394.90 | 533.70 | 672.50 |
| Limited Irr. to R3 then >50% | 14.9 ab | 68.1 a | 2.8 bc | 14.00 | 394.60 | 530.80 | 667.00 |
| Limited Irr. to R5 then >50% | 14.9 b | 69.7 a | 2.5 bcd | 12.50 | 405.70 | 545.10 | 684.50 |
| Full Season Irr. >30% | 14.9 ab | 70.2 a | 2.2 cd | 11.00 | 410.20 | 550.60 | 691.00 |
| Full Season Irr. >50% | 15.0 ab | 72.8 a | 4.0 a | 20.00 | 416.80 | 562.40 | 708.00 |
|  | NS6 | NS |  |  |  |  |  |

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

2Irrigation energy costs were calculated assuming the cost to pump 1 acre-inch of water is $5.00.

3Gross income was calculated based on soybean price, yield, and irrigation cost.

4Gross income minus irrigation energy cost at the expected soybean selling price.

5Treatment means followed by the same letter are not significantly different.

6Treatments were separated using Fisher’s Protected LSD test. NS=not significant.