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

Evaluating the Response of Full Season and Double Cropped 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 and double cropped soybeans.
2) Determine the optimal irrigation management strategy for full season and double cropped soybeans to maximize yield and profitability.

FIVE YEAR AVERAGE YIELD TREND

In research conducted at the University of Delaware Warrington Irrigation Research Farm from 2012 to 2016, trends in soybean response to irrigation strategies are developing. Averaged over five years, there were only slight differences in yield between irrigation strategies in both full season (*Table 1a*) and double cropped (*Table 1b*) soybeans. However, there is a trend that full season and double cropped soybeans may require different irrigation strategies to maximize yield. In full season soybeans, yield with strategies of limited irrigation (>30% soil moisture) to later growth stages were comparable or higher than strategies that provided full irrigation (>50% soil moisture) all season (*Table 1a*). In double cropped soybeans, yield with strategies that provided full irrigation (>50% soil moisture) all season and limited (>30% soil moisture) or no irrigation until R1/R2 were typically slightly higher than strategies of limited irrigation (>30% soil moisture) to later growth stages (*Table 1b*).

In 2015 and 2016 studies, new treatments were included to determine if irrigation could be completely delayed until later growth stages (R3/R4 and R5/R6). Averaged over these two years in the full season study, delaying irrigation to R3/R4 provided similar yield to all other irrigated treatments. There was a slight decrease in yield when irrigation was delayed to R5/R6, however yield was significantly higher than the no irrigation treatment (*Table 1a*). Averaged over these two years in the double crop study, the no irrigation until R3/R4 treatment was comparable to top yielding treatments; however, the no irrigation until R5/R6 treatment yielded significantly less than all other irrigation treatments and was equal to the no irrigation treatment (*Table 1b*). Based on the research results from 2015 and 2016, there is a possibility to completely delay irrigation until at least R3/R4 growth stages.

Table 1a. **Full Season Study** – Irrigation treatment effect on soybean yield averaged over 2, 3, and 4 years and in 2012, 2013, 2014, 2015, and 2016.

	Yield							
Irrigation Treatment[1]	2 yr Avg[2]	3 yr Avg[3]	5 yr avg[4]	2012	2013	2014	2015	2016
	bu/A							
No Irr.	40 c[5]	65 e	56 b	54 c	69 abc	73 b	25 c	55 c
No Irr. to R1/R2 then >50%	73 ab	70 bc	72 a	63 b	71 ab	76 ab	74 ab	72 ab
No Irr. to R3/R4 then >50%	73 ab	--	--	--	--	--	80 a	66 b
No Irr. to R5/R6 then >50%	68 b	--	--	--	--	--	68 b	68 ab
Limited Irr. to R1/R2 then >50%	75 ab	70 abc	72 a	67 ab	69 abc	75 ab	76 ab	73 ab
Limited Irr. to R3/R4 then >50%	70 ab	72 a	72 a	66 ab	73 a	77 a	73 ab	67 ab
Limited Irr. to R5/R6 then >50%	73 ab	72 ab	72 a	70 a	71 ab	73 b	72 b	73 ab
Limited Irr. to R1/R2 then >50% to R3/R4 then >70%	--	70 bc	--	63 b	71 ab	75 ab	--	--
Full Season Irr. >30%	71 ab	--	--	--	--	--	77 ab	65 b
Full Season Irr. >50%	75 a	67 de	70 a	63 b	65 d	74 ab	75 ab	75 a
KanSched2 (ET) >50%	--	68 cd	--	65 ab	66 cd	73 b	--	--

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

[2]Data combined from 2015 and 2016.

[3]Data combined from 2012, 2013, and 2014.

[4]Data combined from 2012, 2013, 2014, 2015, and 2016.

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

Table 1b. **Double Cropped Study** – Irrigation treatment effect on soybean yield averaged over 2, 3, and 4 years and in 2012, 2013, 2014, 2015, and 2016.

Irrigation Treatment[1]	Yield							
	2 yr Avg[2]	3 yr Avg[3]	5 yr avg[4]	2012	2013	2014	2015	2016
	bu/A							
No Irr.	42 b[5]	44 d	44 d	58 a	31 e	42 d	40 b	44 c
No Irr. to R1/R2 then >50%	51 a	51 bc	53 abc	58 a	42 bc	52 bc	50 a	52 ab
No Irr. to R3/R4 then >50%	52 a	--	--	--	--	--	50 a	54 a
No Irr. to R5/R6 then >50%	44 b	--	--	--	--	--	40 b	48 b
Limited Irr. to R1/R2 then >50%	54 a	53 a	54 ab	61 a	42 abc	55 a	53 a	54 a
Limited Irr. to R3/R4 then >50%	52 a	49 c	51 c	59 a	39 cd	50 c	52 a	51 ab
Limited Irr. to R5/R6 then >50%	52 a	50 bc	51 bc	59 a	38 d	54 ab	51 a	52 ab
Limited Irr. to R1/R2 then >50% to R3/R4 then >70%	--	50 c	--	59 a	37 d	53 ab	--	--
Full Season Irr. >30%	52 a	--	--	--	--	--	52 a	53 a
Full Season Irr. >50%	53 a	53 a	55 a	60 a	45 a	54 ab	52 a	54 a
KanSched2 (ET) >50%	--	52 ab	--	59 a	43 ab	55 a	--	--

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

[2]Data combined from 2015 and 2016.

[3]Data combined from 2012, 2013, and 2014.

[4]Data combined from 2012, 2013, 2014, 2015, and 2016.

[5]Treatment 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 2, 3, and 4 years and in 2012, 2013, 2014, 2015, and 2016.

	Irrigation Applied						
Irrigation Treatment[1]	2 yr Avg[2]	5 yr avg[3]	2012	2013	2014	2015	2016
	inches						
No Irr.	0.0 d[4]	0.0 d	0.0 d	0.0 d	0.0 e	0.0 e	0.0 c
No Irr. to R1/R2 then >50%	8.0 a	6.0 b	6.8 abc	5.4 abc	2.9 cd	8.8 ab	7.2 a
No Irr. to R3/R4 then >50%	7.7 a	--	--	--	--	8.0 ab	7.3 a
No Irr. to R5/R6 then >50%	5.9 bc	--	--	--	--	5.6 cd	6.1 ab
Limited Irr. to R1/R2 then >50%	7.9 a	6.6 b	8.1 abc	5.5 abc	3.6 c	9.6 a	6.1 ab
Limited Irr. to R3/R4 then >50%	7.6 a	5.9 bc	6.5 bc	4.3 c	3.9 c	7.3 bcd	7.8 a
Limited Irr. to R5/R6 then >50%	7.2 ab	5.3 c	5.3 c	4.8 bc	1.9 d	7.5 bc	6.9 ab
Limited Irr. to R1/R2 then >50% to R3/R4 then >70%	--	--	9.6 a	7.0 a	5.5 b	--	--
Full Season Irr. >30%	5.1 c	--	--	--	--	5.3 d	4.9 b
Full Season Irr. >50%	8.1 a	7.5 a	8.3 ab	6.3 ab	5.8 b	8.4 ab	7.8 a
KanSched2 (ET) >50%	--	--	9.0 ab	5.9 abc	9.0 a	--	--

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

[2]Data combined from 2015 and 2016.

[3]Data combined from 2012, 2013, 2014, 2015, and 2016.

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

Table 1d. **Double Cropped Study** – Irrigation treatment effect on amount of irrigation applied averaged over 2, 3, and 4 years and in 2012, 2013, 2014, 2015, and 2016.

Irrigation Treatment[1]	Irrigation Applied						
	2 yr Avg[2]	5 yr avg[3]	2012	2013	2014	2015	2016
	inches						
No Irr.	0.0 e[4]	0.2 c	0.5 d	0.5 b	0.0 d	0.0 f	0.0 d
No Irr. to R1/R2 then >50%	4.8 bc	4.8 ab	4.5 abc	6.0 a	4.2 bc	5.5 ab	4.0 abc
No Irr. to R3/R4 then >50%	3.8 c	--	--	--	--	3.7 d	3.9 abc
No Irr. to R5/R6 then >50%	2.7 d	--	--	--	--	2.4 e	2.9 c
Limited Irr. to R1/R2 then >50%	5.1 ab	5.3 a	5.8 ab	6.1 a	4.3 abc	5.6 ab	4.6 abc
Limited Irr. to R3/R4 then >50%	5.2 ab	5.0 a	5.6 ab	5.6 a	3.4 c	4.9 bc	5.4 a
Limited Irr. to R5/R6 then >50%	4.9 b	4.1 b	2.2 cd	4.7 a	3.6 c	5.0 bc	4.8 ab
Limited Irr. to R1/R2 then >50% to R3/R4 then >70%	--	--	5.9 ab	5.5 a	5.4 ab	--	--
Full Season Irr. >30%	3.8 c	--	--	--	--	4.0 c	3.5 bc
Full Season Irr. >50%	6.1 a	5.4 a	3.7 bc	6.7 a	4.5 abc	6.6 a	5.5 a
KanSched2 (ET) >50%	--	--	6.6 a	5.3 a	5.4 a	--	--

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

[2]Data combined from 2015 and 2016.

[3]Data combined from 2012, 2013, 2014, 2015, and 2016.

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

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

2016 (5th year of trials).

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/R2 and R5/R6. There was a significant difference between the full season >50% irrigation treatment and the no irrigation to R3/R4 and the full season irrigation >30%.

In the double crop soybean study, soybeans were planted on July 12. The amount of water applied based on the irrigation strategy ranged from 2.9" to 5.5". Average yield in plots that received irrigation ranged from 48 to 54 bu/A compared to 44 bu/A in plots that received no irrigation. All irrigation strategies, except no irrigation to R5/R6 then >50% soil moisture to maturity (48 bu/A), yielded similarly from 51 to 54 bu/A. Delaying irrigation until R5/R6 slightly decreased yield.

2015 (4th year of trials).

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/R4 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/R6 then >50% available moisture to maturity (68 bu/A) and limited irrigation to R5/R6 then >50% soil moisture to maturity (72 bu/A).

In the double crop study, soybeans were planted on July 8. The amount of water applied based on the irrigation strategy ranged from 2.4" to 6.6". Average yield in plots that received irrigation ranged from 40 to 53 bu/A compared to 40 bu/A in plots that received no irrigation. All irrigation strategies, except no irrigation to R5/R6 then >50% soil moisture to maturity (40 bu/A), yielded similarly from 50 to 53 bu/A. With the lack of rainfall in August, waiting to start irrigation until R5/R6 significantly reduced yields compared to starting irrigation before R3/R4.

2014 (3rd year of trials). 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.

In the double crop study, soybeans were planted on July 9. Average yield in plots that received irrigation ranged from 50 to 55 bu/A compared to 42 bu/A in plots that received no irrigation. The amount of water applied based on the irrigation strategy ranged from 3.4 in. to 5.4 in. There was only a slight difference in yield between irrigated treatments. Soybeans planted in 7.5 in., 15 in., and 30 in. row widths yielded similarly to each irrigation strategy, but there was an overall yield difference between row widths. Average soybean yield was 56 bu/A in 7.5 in.rows, 51 bu/A in 15 in. rows, and 50 bu/A in 30 in. rows

2013 (2nd year of trials). 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/R4 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/R2 and limited irrigation to R1/R2 and R5/R6, 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.

In the double crop study, soybeans were planted on July 19. Average yield in plots that received irrigation ranged from 38 to 45 bu/A compared to 31 bu/A in plots that received no irrigation. The amount of water applied based on the irrigation strategy ranged from 4.7" to 6.7". The irrigation strategy that produced the greatest yield (45 bu/A) was when irrigation was applied to maintain soil moisture >50% all season. Yield from irrigation strategies where soil moisture was maintained >50% available moisture at R1/R2 until maturity, except the treatment of limited irrigation to R1/R2 then >50% available

moisture to R3/R4 then >70% available moisture to maturity, yielded similarly at 42 to 45 bu/A. The limited irrigation to R3/R4 then >50% available moisture to maturity, limited irrigation to R5/R6 then >50% available moisture to maturity, and limited irrigation to R1/R2 then >50% available moisture to R3/R4 then >70% available moisture to maturity strategies produced the lowest yields at 39, 38, and 37 bu/A, respectively. 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 41 bu/A in 7.5" rows, 41 bu/A in 15" rows, and 37 bu/A in 30" rows.

2012 (1st year of trials). 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/R6 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.

In the double crop study, average yield in plots that received irrigation ranged from 58 to 61 bu/A compared to 58 bu/A in plots that received no irrigation. The amount of water applied based on the irrigation strategy ranged from 2.2" to 6.6". The above average rainfall in August had a significant effect on soybean yield. Soybeans in all row widths responded similarly to each irrigation strategy, but there was an overall yield difference between row widths. Yield was greatest in the 15" rows at 64 bu/A, followed by the 30" rows at 58 bu/A, and then the 7" rows at 55 bu/A. Final stand in the 7" rows was 107,000 plants/A compared to 169,522 plants/A in the 15" rows, and 154,427 plants/A in the 30" rows. The reduced plant stand in the 7" rows compared to the 15" and 30" rows may have limited yield potential.

MATERIALS AND METHODS

Two studies were conducted in 2016 to determine the response of full season and double cropped 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. In both projects, the plots measured 60 ft by 60 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 to R2) then >50% soil moisture.
3. No irrigation until pod development (R3 to R4) then >50% moisture.

4. No irrigation until seed development (R5 to R6) then >50% soil moisture.
5. Limited irrigation (>30% soil moisture) until flowering (R1 to R2) then >50% soil moisture.
6. Limited irrigation (>30% soil moisture) until pod development (R3 to R4) then >50% moisture.
7. Limited irrigation (>30% soil moisture) until seed development (R5 to R6) 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. In the full season study, soybeans were grown under conventional tillage practices, whereas soybeans in the double crop study were planted no-till into small grain stubble following wheat harvest. Soybeans in both studies were planted in 15 in. rows with a Monosem planter. Planting dates, soybean varieties, seeding rates, pesticide applications, and harvest dates for both studies 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	Double Crop Study
Planting Date	6/3/16	7/12/16
Variety	Asgrow 4135	Asgrow 4135
Target Seeding Rate/A	165,000	200,000
Pesticide Applications		
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
Harvest Date	10/31/16	11/1/16

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*), plant heights, and NDVI (Normalized Difference Vegetation Index) were recorded on multiple dates. In addition, lodging was recorded at harvest. 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 the Proc GLM procedure in SAS 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 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	728/16	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

Figure 1. Bi-weekly rainfall total at the study site in Harbeson, DE in 2016.

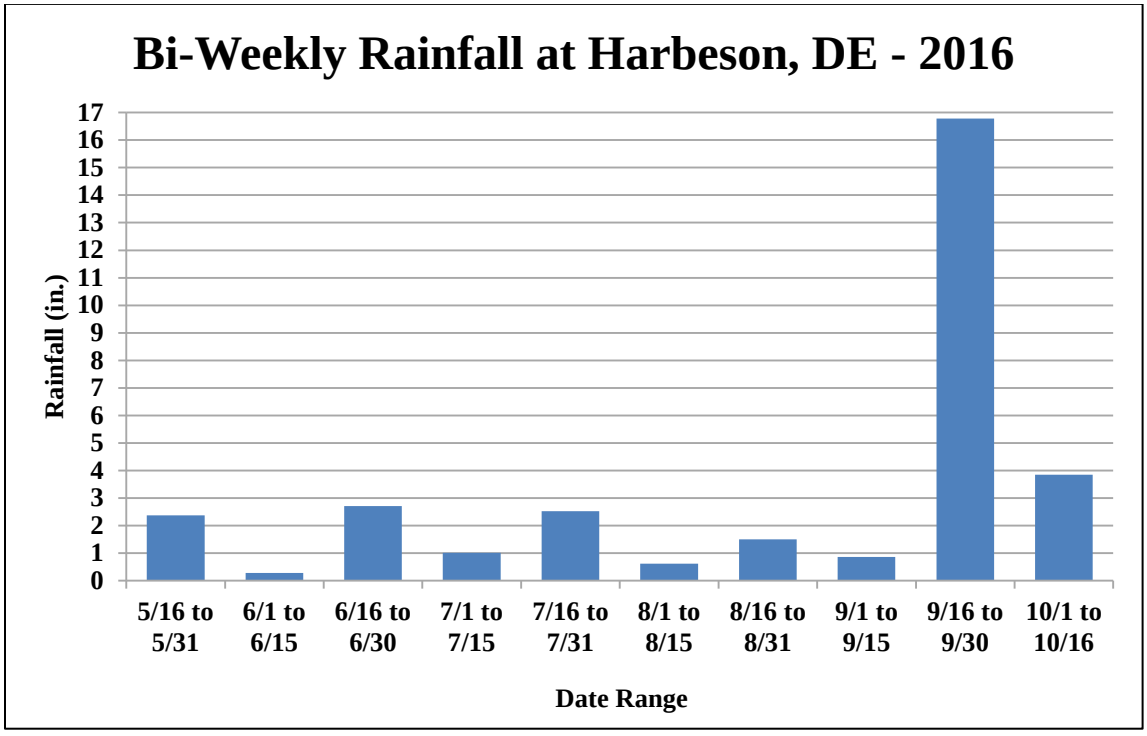


Table 4. Total monthly rainfall, average daily rainfall, and time periods with low rainfall.

Time Period	Rainfall Total	Average Daily Rainfall
	—— Inches ——	—— Inches ——
June	2.99	0.10
July	3.53	0.11
August	2.12	0.07
September	17.64	0.59
October	4.19	0.14
August 1 to September 15	2.98	0.06

RESULTS AND DISCUSSION

In-Season Rainfall. *Figure 1* shows the bi-weekly rainfall at the study site in Harbeson, DE in 2016. Rainfall was below average in June (2.99"), July (3.53"), and August (2.12") (*Figure 1 and Table 4*). Rainfall total from August 1 to September 15 was 2.98", which averaged 0.06" per day over that time period.

Irrigation Applied. Bi-weekly and total irrigation applied for each treatment in the full season and double crop studies are shown in *Figure 2* and *Figure 3*, respectively.

Full Season Study – Irrigation applied for all irrigated treatments ranged from 4.9 in. to 7.8 in. (*Table 6; Figure 2*).

Double Crop Study – Irrigation applied for all irrigated treatments ranged from 2.9 in. to 5.5 in. (*Table 8; Figure 3*).

Soybean Growth.

Full Season Study – Soybean heights were measured on 7/18, 8/8, 8/17, 8/31, and 10/31 (*Table 5*). NDVI was recorded with a handheld Greenseeker on 7/18, 8/8, 8/17, and 8/31.

Plant Height by Irrigation Treatment. Maximum soybean height was obtained by R6 (recorded on 8/31). Heights ranged from 34.8 in. to 41.3 in (*Table 5*). All treatments that initiated irrigation by R1/R2 resulted in the greatest heights, which ranged from 38.3 in to 41.0 in. Soybean heights in the no irrigation to R3/R4 and R5/R6 were 34.2 in. and 35.1 in. respectively and were similar to the no irrigation treatment (34.7 in.) The below average rainfall in July and early August before irrigation was initiated had an effect on soybean heights in these no irrigation treatments to the later growth stages.

Double Crop Study – Soybean heights were measured on 8/17, 8/29, 9/7, 9/23, and 10/31. NDVI was recorded on 8/17, 8/29, 9/7, and 9/23.

Plant Height by Irrigation Treatment. Maximum soybean height was obtained by R5 (recorded on 9/7). All irrigated treatments, except no irrigation until R5/R6, resulted in similar heights on 9/7 (*Table 7*). Heights ranged from 28.6 in. to 30.5 in. Height in the no irrigation treatment until R5/R6 was 28.1 in.

Lodging and Yield.

Full Season Study – Soybeans were harvested on 10/31. Lodging ratings were recorded before harvest.

Lodging by Irrigation Treatment. There were only slight differences in lodging between all irrigated treatments, which ranged from 1.6 to 3.0 on a scale of 0 to 5 (0=no lodging; 5 =maximum lodging) (*Table 6*). Lodging in the no irrigation treatment was 0.6.

Yield by Irrigation Treatment. 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 (*Figure 2*; *Table 6*). 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/R2 and R5/R6. There was a significant difference between the full season >50% irrigation treatment and the no irrigation to R3/R4 and the full season irrigation >30%.

Double Crop Study – Soybeans were harvested on 11/1. There was no lodging to rate.

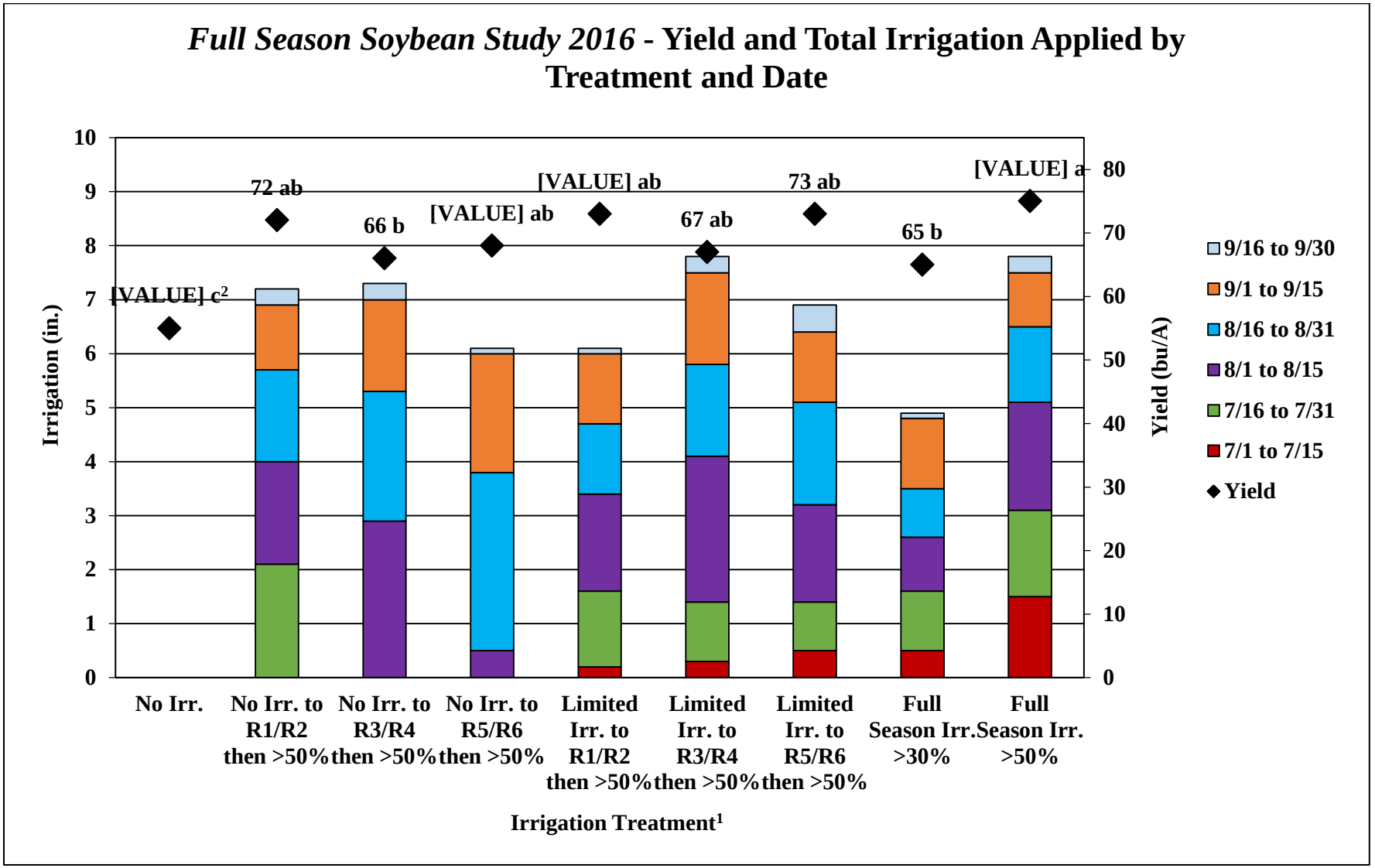
Yield by Irrigation Treatment. Average yield in plots that received irrigation ranged from 48 to 54 bu/A compared to 44 bu/A in plots that received no irrigation (*Figure 3; Table 8*). All irrigation strategies, except no irrigation to R5/R6 then >50% soil moisture to maturity (48 bu/A), yielded similarly from 51 to 54 bu/A. Delaying irrigation until R5/R6 slightly decreased yield.

Economics.

Full Season Study – The top 3 most profitable treatments based on yield and total irrigation applied were 1) Full season irrigation >50%, 2) Limited irrigation to R1/R2, and 3) Limited irrigation to R5/R6.

Double Crop Study – The top 3 most profitable treatments based on yield and total irrigation applied were 1) No irrigation to R3/R4, 2) Limited irrigation to R1/R2, and 3) Full season irrigation >50%.

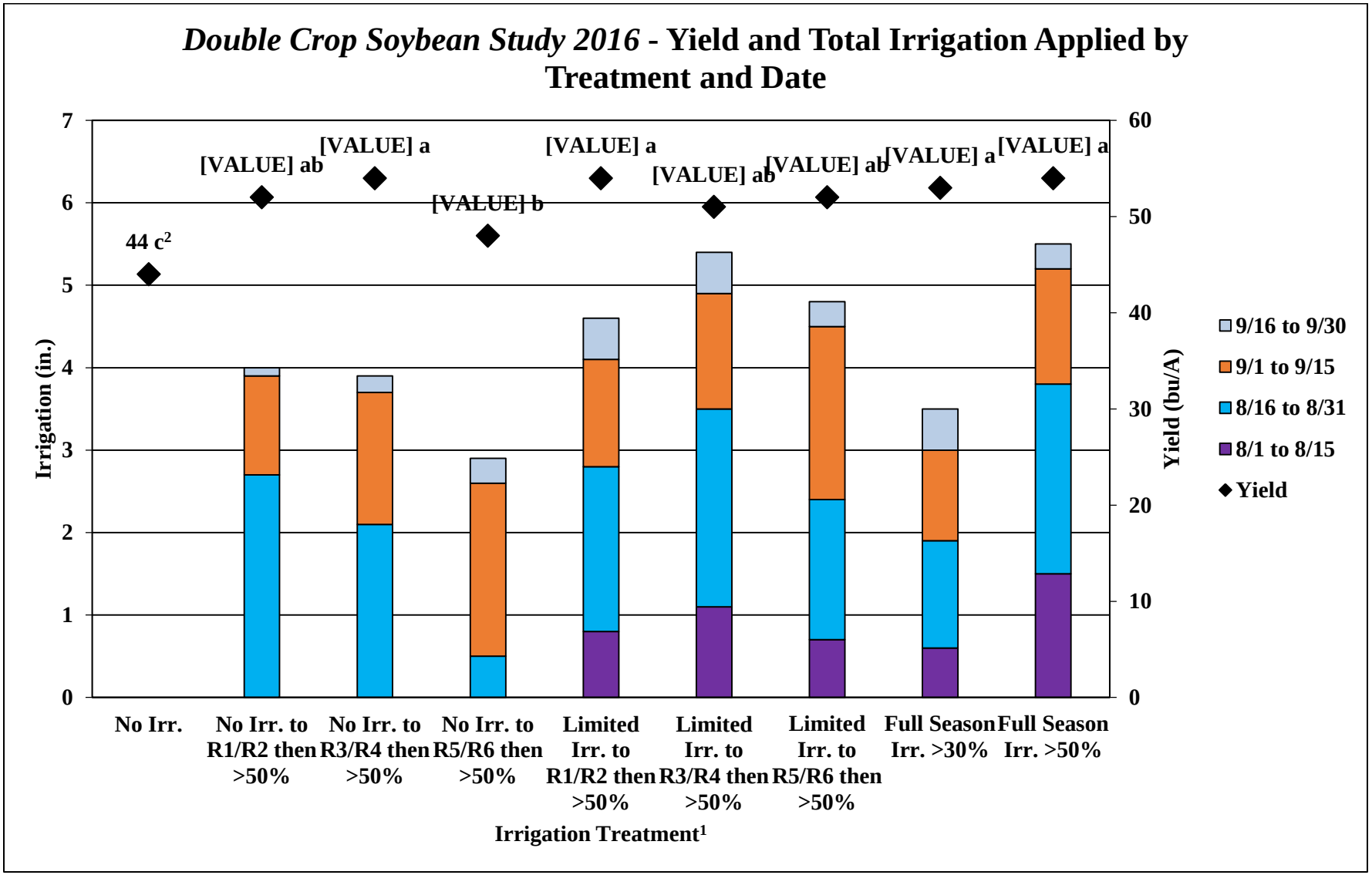
Figure 2. Full Season Study – Soybean yield and total irrigation applied bi-weekly by treatment. Each color represents the total amount of irrigation applied during the date range listed. The top of the bar column represents the total irrigation applied for the season.



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

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

Figure 3. Double Crop 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.



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

[2]Treatment 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					NDVI[2]			
Irrigation Treatment[1]	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
	in.								
No Irr.	12.6 a[3]	30.8 bc	34.7 d	35.2 cd	32.9 c	0.81 a	0.89 cd	0.89 c	0.82 d
No Irr. to R1/R2 then >50%	12.5 a	32.7 ab	39.6 ab	40.3 ab	38.6 ab	0.83 a	0.91 ab	0.91 ab	0.87 ab
No Irr. to R3/R4 then >50%	12.7 a	29.5 c	34.2 d	34.8 d	35.1 abc	0.80 a	0.88 d	0.90 c	0.84 c
No Irr. to R5/R6 then >50%	13.0 a	31.3 abc	35.1 cd	35.9 cd	35.2 abc	0.83 a	0.90 bc	0.90 abc	0.85 bc
Limited Irr. to R1/R2 then >50%	12.8 a	31.7 abc	38.8 ab	39.2 ab	37.5 ab	0.80 a	0.91 ab	0.90 abc	0.87 ab
Limited Irr. to R3/R4 then >50%	13.0 a	30.6 bc	37.1 bcd	37.6 bcd	34.4 bc	0.82 a	0.90 abc	0.90 bc	0.86 abc
Limited Irr. to R5/R6 then >50%	12.8 a	31.3 abc	37.0 bcd	37.7 bcd	36.6 abc	0.79 a	0.90 abc	0.91 ab	0.87 ab
Full Season Irr. >30%	13.0 a	32 ab	38.3 abc	38.4 abc	36.8 abc	0.82 a	0.91 abc	0.90 abc	0.85 bc
Full Season Irr. >50%	13.6 a	33.2 a	41.0 a	41.3 a	39.6 a	0.84 a	0.91 a	0.91 a	0.88 a
LSD[4]	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.

[4]Treatments 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.

Irrigation Treatment[1]	Lodging[2]	Moisture	Yield	Total Irrigation Applied	Irrigation Energy Cost[3]	Gross Income minus Irrigation Energy Cost[4]		
						$6.00/bu[5]	$8.00/bu	$10.00/bu
	#	%	bu/A	in.	$/Acre	$		
No Irr.	0.6 b[6]	12.5 a	55 c	0.0 c	0.00	330	440	550
No Irr. to R1/R2 then >50%	1.8 ab	12.2 bc	72 ab	7.2 a	36.00	396	540	684
No Irr. to R3/R4 then >50%	1.6 ab	12.2 bc	66 b	7.3 a	36.50	360	492	624
No Irr. to R5/R6 then >50%	2.2 a	12.1 c	68 ab	6.1 ab	30.50	378	514	650
Limited Irr. to R1/R2 then >50%	2.2 a	12.3 abc	73 ab	6.1 ab	30.50	408	554	700
Limited Irr. to R3/R4 then >50%	1.6 ab	12.2 bc	67 ab	7.8 a	39.00	363	497	631
Limited Irr. to R5/R6 then >50%	2.0 ab	12.3 abc	73 ab	6.9 ab	34.50	404	550	696
Full Season Irr. >30%	2.4 a	12.2 bc	65 b	4.9 b	24.50	366	496	626
Full Season Irr. >50%	3.0 a	12.4 ab	75 a	7.8 a	39.00	411	561	711
LSD[7]	NS	NS						

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

[2]Lodging was rated on a scale of 0 to 5 (0 = no lodging; 5 = maximum lodging).

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

[4]Gross income was calculated based on soybean price, yield, and irrigation cost.

[5]Gross income minus irrigation energy cost at the expected soybean selling price.

[6]Treatment means followed by the same letter are not significantly different.

[7]Treatments were separated using Fisher's Protected LSD test. NS=not significant.

Table 7. Double Crop Soybean Study - Irrigation treatment effect on soybean plant height and NDVI.

	Plant Height					NDVI[2]			
Irrigation Treatment[1]	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
	in.								
No Irr.	12.7 abc[3]	21.7 b	26.6 c	25.6 c	26.1 c	0.81 ab	0.81 c	0.84 b	0.87 d
No Irr. to R1/R2 then >50%	13.0 abc	24.6 a	30.5 a	30.2 ab	30.1 ab	0.82 ab	0.87 ab	0.88 a	0.89 abc
No Irr. to R3/R4 then >50%	13.2 ab	23.6 ab	30.5 a	29.9 ab	30.0 ab	0.84 a	0.87 ab	0.89 a	0.89 c
No Irr. to R5/R6 then >50%	11.8 c	22.7 ab	28.1 bc	27.8 bc	28.1 bc	0.79 b	0.86 b	0.88 a	0.89 abc
Limited Irr. to R1/R2 then >50%	12.6 bc	24.4 a	30.4 ab	30.7 a	29.9 ab	0.83 a	0.89 ab	0.89 a	0.89 ab
Limited Irr. to R3/R4 then >50%	13.2 ab	24.6 a	29.7 ab	29.5 ab	29.1 ab	0.82 ab	0.87 ab	0.88 a	0.89 abc
Limited Irr. to R5/R6 then >50%	13.3 ab	24.6 a	30.3 ab	29.8 ab	29.7 ab	0.83 a	0.86 b	0.88 a	0.88 c
Full Season Irr. >30%	12.8 abc	23.1 ab	28.6 abc	29.5 ab	28.7 abc	0.82 ab	0.88 ab	0.89 a	0.88 c
Full Season Irr. >50%	14.0 a	25.1 a	30.7 a	31.2 a	31.2 a	0.84 a	0.89 a	0.89 a	0.89 a
LSD[4]	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.

[4]Treatments were separated using Fisher's Protected LSD test. NS=not significant.

Table 8. Double Crop 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.

Irrigation Treatment[1]	Moisture	Yield	Total Irrigation Applied	Irrigation Energy Cost[2]	Gross Income minus Irrigation Energy Cost[3]		
					$6.00/bu[4]	$8.00/bu	$10.00/bu
	— % —	— bu/A —	— in. —	- $/Acre -	——— $ ———		
No Irr.	12.0 c[5]	44 c	0.0 d	0.00	264	352	440
No Irr. to R1/R2 then >50%	12.2 abc	52 ab	4.0 abc	20.00	292	396	500
No Irr. to R3/R4 then >50%	12.3 a	54 a	3.9 abc	19.50	305	413	521
No Irr. to R5/R6 then >50%	12.0 c	48 b	2.9 c	14.50	274	370	466
Limited Irr. to R1/R2 then >50%	12.0 c	54 a	4.6 abc	23.00	301	409	517
Limited Irr. to R3/R4 then >50%	12.0 c	51 ab	5.4 a	27.00	279	381	483
Limited Irr. to R5/R6 then >50%	12.3 ab	52 ab	4.8 ab	24.00	288	392	496
Full Season Irr. >30%	12.3 ab	53 a	3.5 bc	17.50	301	407	513
Full Season Irr. >50%	12.1 c	54 a	5.5 a	27.50	297	405	513
LSD[6]	NS						

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

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

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

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

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

[6]Treatments were separated using Fisher's Protected LSD test. NS=not significant.