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FINAL REPORT

Project Title: Row-Crop Irrigation Science Extension and Research (RISER) Program—Irrigation Thresholds

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Objective I: Determine if soybean grain yield, IWUE, and net return above irrigation cost could be optimized using a static irrigation threshold or if the irrigation threshold should be changed as a function of plant growth stage.

EXECUTIVE SUMMARY

The Mississippi River Valley Alluvial Aquifer (MRVAA) is declining precipitously due to withdrawal of water to irrigate row-crops. It is surmised that using scientific irrigation scheduling techniques for soybean will reduce this withdrawal from the MRVAA.

The objective of this research was to determine if soybean grain yield, net returns above irrigation costs, and IWUE are optimized using a static irrigation threshold or if the irrigation threshold should be changed as a function of plant growth stage.

Research was conducted at the Delta Research and Extension Center, Stoneville, Mississippi from 2015 through 2017 on a Dundee silty clay loam. Asgrow 4632 (MG IV soybean variety) was used. Treatments were in a split-plot arrangement within a randomized complete block design with four replications. The whole-plot was soybean growth stage (VN-R2, R3-R4, R5-R6.5), and the sub-plot was irrigation threshold (-50, -85 and -125 kPa). Three controls were included for comparison: nonirrigated, and season-long irrigation using static -50 and -85 kPa thresholds.

Irrigation was applied when the weighted average of the soil water potential in the 0- to 61-cm rooting depth reached treatment threshold as measured by Watermark Model 200SS soil water potential sensors that were installed at 15-, 30-, and 61-cm soil depths within one replication. For season-long, static treatments, irrigation thresholds were -50 and -85 kPa. For dynamic thresholds, treatments were irrigated based on their specific growth stage and kPa threshold. Irrigation was terminated at the R6.5 growth stage as recommended by the Mississippi State University Extension Service.

Plots were furrow-irrigated with water being pumped through 30.5-cm diameter lay-flat poly-ethylene tubing laid perpendicular to the soybean rows. Computerized hole selection was calculated with the Pipe Hole And Universal Crown Evaluation Tool (PHAUCET) version 8.2.20 (USDA-NRCS, Washington, DC). Agronomic practices outside of irrigation scheduling

were conducted according to Mississippi State University Extension Service recommendations for regional producers.

The following results are indicated by data in the accompanying tables.

- In this study, all irrigation threshold treatments except the R5-R6/-125 kPa treatment produced yields that were similar, and net returns to each treatment followed the same pattern as yield (Table 1).

- Static irrigation thresholds (-50 and -85 kPa) yielded more than nonirrigated, but static irrigation threshold treatment yields were not different from one another (Table 2).

- IWUE for the static -85 kPa threshold treatment was 2.6 times greater than that for the -50 kPa treatment, while yield and net returns to both treatments were similar (Table 2).

These results indicate that soybean grain yield, net returns above irrigation costs, and IWUE are optimized using a season-long, static -85 kPa threshold**.** Moreover, prior research conducted at the farm scale encompassing approximately 23,000 km^2 showed that -85 to -100 kPa thresholds utilized season-long did not adversely affect irrigated soybean grain yield or net returns above irrigation costs on soil textures ranging from silt loam to clay.

Overall, results from this research indicate that soybean producers in the Midsouth and other regions that irrigate using lay-flat poly-ethylene tubing can adopt a static, season-long -85 kPa soil moisture sensor threshold for early-planted soybean without adversely affecting yield or on-farm profitability, while concurrently decreasing the demand on depleted groundwater resources.

Table 1. Mean soybean grain yield, irrigation water use efficiency (IWUE), and net returns above irrigation costs for a study conducted in Stoneville, MS from 2015 through 2017.

Growth Stage	kPa Threshold	Yield*	IWUE	Net Return*
		Bu/acre	Bu/acre/inch	$/acre
VN-R2	50	59.6 ab	1.43	491.40 a
VN-R2	85	60.4 ab	2.53	510.03 a
VN-R2	125	60.1 ab	2.15	504.21 a
R3-R4	50	58.3 bc	2.56	487.02 ab
R3-R4	85	58.8 abc	2.15	488.96 ab
R3-R4	125	60.1 ab	2.38	504.18 a
R5-R6	50	61.9 a	1.09	495.03 a
R5-R6	85	59.7 ab	1.32	487.92 ab
R5-R6	125	55.7 c	2.00	462.35 b

*Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

Table 2. Mean soybean grain yield, irrigation water use efficiency (IWUE), and net returns above irrigation costs for season-long, static kPa threshold treatments for a study conducted in Stoneville, MS from 2015 through 2017.

kPa Threshold	Yield*	IWUE*	Net Return*
50	62.4 a	6.48 b	485.53 b
85	59.7 a	17.08 a	493.72 ab
Non-irrigated	54.0 b	---	525.79 a

*Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

ABSTRACT

The Mississippi River Valley Alluvial Aquifer (MRVAA) is declining precipitously due to irrigation withdrawal for row-crops. The development of scientific irrigation scheduling techniques for soybean (*Glycine max* L.) will reduce withdrawal from the MRVAA.

The objective of this research was to determine if soybean grain yield, irrigation water use efficiency (IWUE), and net return above irrigation cost could be optimized using a static irrigation threshold or if the irrigation threshold should be changed as a function of plant growth stage. Treatments were arranged as a split-plot within a randomized complete block design with four replications of each treatment on a Dundee silty clay loam from 2015 through 2017.

The whole plot factor was growth stage (VN to R2, R3 to R4, R5 to R6.5), and the sub-plot factor was irrigation threshold (-50, -85 and -125 kPa). A nonirrigated and season-long, static irrigation thresholds (-50 and -85 kPa) were included as controls. For the dynamic threshold, growth stage and irrigation threshold interacted to effect yield ($P = 0.0012$) and net return above irrigation cost ($P = 0.0412$), but not IWUE ($P = 0.2696$). Dynamic thresholds only influenced yield and net returns when a -125 kPa threshold was maintained during the critical pod fill growth stage. Season-long, static thresholds affected yield ($P \leq 0.0001$) and IWUE ($P \leq 0.0001$), but not net return above irrigation cost ($P = 0.0537$). Static irrigation thresholds yielded 13% more than nonirrigated, but static irrigation thresholds yields were not different from one another. Irrigation water use efficiency for the static -85 kPa threshold was 2.6-fold greater than the static -50 kPa. These results indicate soybean grain yield, IWUE, and net returns above irrigation cost are optimized with a static irrigation threshold of -85 kPa.

INTRODUCTION

In the Midsouth, the majority of planted soybean hectares are furrow-irrigated, and the primary irrigation source is the Mississippi River Valley Alluvial Aquifer (MRVAA) (Bryant et al. 2017; Massey et al. 2017). Agricultural withdrawal exceeds the MRVAA's recharge by a rate of 370 million cubic meters of water per year (Wax et al. 2009; Guzman et al. 2014).

Nationally, Mississippi ranks eighth in terms of irrigated cropland area (USDA NASS 2013), and soybean accounts for the largest amount of irrigation water applied to row crops in the state (Massey et al. 2017). From 2002-2013, average season-long irrigation water applied to soybean in Mississippi was 2,800 m^3 ha^{-1}, and irrigation rates increased circa 200 m^3 ha^{-1} y^{-1} (Massey et al. 2017). With approximately 534,000 irrigated soybean hectares in the Mississippi Delta, there is critical need for improving irrigation water use efficiency (IWUE).

Currently, the majority of irrigated hectares in the Delta region of Arkansas and Mississippi is planted to maturity group (MG) IV soybean that are furrow-irrigated using a conventional continuous flow delivery system (Bryant et al. 2017). Depending on soil texture, local producers base irrigations upon a 7- to 10-day calendar schedule, initiating during early reproductive growth and terminating near physiological maturity (Personal communication Trent Irby). To optimize Mississippi Delta production practices, the impact that soil moisture sensor-based irrigation scheduling has on IWUE and net returns above irrigation costs needs to be evaluated.

Nationally, less than 15% of producers use scientific irrigation scheduling tools such as daily crop evapotranspiration (ET) and soil moisture sensors to schedule irrigations. As of 2013, 47% of producers scheduled irrigations based upon the condition of the crop (visual), 24% according to the feel of the soil, 9.6% utilized daily crop evapotranspiration (ET), and only 4.6% irrigated based upon a soil moisture sensing device (USDA-NASS, 2013). Even in regions where severe water shortages occur, the adoption of scientific irrigation scheduling tools is less than 2% (Frisvold and Deva 2012). However, use of soil moisture sensors has increased in Mississippi since 2008, with 31% of producers utilizing soil moisture sensors in their irrigated fields (Mississippi Soybean Promotion Board, 2017).

Soil moisture sensors are a scientific tool that enable producers to optimize irrigation timing, application efficiency, yield, and IWUE. Specifically, soil moisture sensors determine soil moisture content in the active rooting zone, when to initiate irrigation events, irrigation application volumes, and depth of wetting fronts (Hanson et al. 2000). Several studies have reported that use of soil moisture sensors has increased yield of summer crops in average climatic years 13-40% (Josipović et al. 2011; Marković et al. 2012; Marković 2013). In Mississippi, amount of irrigation water applied to soybean when managed with a scheduling tool was reduced by 50% compared to when an irrigation scheduling tool was not utilized (Krutz et al. 2014) and IWUE increased 36% when IWM practices were utilized (Bryant et al. 2017).

Soybean grain yield is affected by the timing and duration of water-deficit stress. At any soybean growth stage, drought stress can reduce yield (Yazar et al. 1989); however, yield loss due to drought stress is likely more severe during the reproductive growth stages (Doorenbus and Kassam, 1979; Constable and Hearn, 1980; Meckel et al., 1984; Foroud et al. 1993). There is insufficient research to determine if specific reproductive growth stages are more sensitive to drought stress than others, and there is a paucity of data indicating at what specific kPa threshold yield loss occurs. The objective of this research was to determine if soybean grain yield, IWUE, and net return above irrigation cost could be optimized using a static irrigation threshold or if the irrigation threshold should be changed as a function of plant growth stage.

MATERIALS AND METHODS

Site Description and Experimental Design

Research was conducted at the Delta Research and Extension Center, Stoneville, Mississippi from 2015 through 2017 on a Dundee silty clay loam (Fine-silty, mixed, active, thermic Typic Endoaqualfs). Asgrow 4632 was planted at a depth of 3-cm at 345,800 seeds ha^{-1} into 1.04-m-wide raised beds with a John Deere Maxemerge 4-row planter. Experimental units were 31.25-m long by 4.16-m wide. Treatments were in a split-plot arrangement within a randomized complete block design with four replications. The whole-plot was soybean growth stage (VN-R2, R3-R4, R5-R6.5), and the sub-plot was irrigation threshold (-50, -85 and -125 kPa). Three controls were included for comparison: nonirrigated, and season-long irrigation, and static -50 and -85 kPa thresholds.

Sensor Based Scheduling

Irrigation was applied when the weighted average of the soil water potential in the 0- to- 61-cm rooting depth reached treatment threshold as measured by Watermark Model 200SS soil water potential sensors (Irrometer Company Inc., Riverside, CA) that were installed at 15, 30, and 61-cm soil depths within one replication. For season-long, static treatments, irrigation thresholds were -50 and -85 kPa. For dynamic thresholds, treatments were irrigated based upon their specific growth stage and kPa threshold (Table 1). Irrigation was terminated at the R6.5 growth stage as recommended by the Mississippi State University Extension Service.

Irrigation Delivery

Plots were furrow-irrigated with water being pumped through 30.5-cm diameter lay-flat poly-ethylene tubing (Delta Plastics, Little Rock, AR) laid perpendicular to the soybean rows. Computerized hole selection was calculated with the Pipe Hole And Universal Crown Evaluation Tool (PHAUCET) version 8.2.20 (USDA-NRCS, Washington, DC). Input parameters for computerized hole selection were implemented as described by Bryant et al. (2017). Flow rate at the field inlet was determined with a M^{c}Crometer flow tube with attached M^{c}Propeller bolt-on saddle flowmeter (M^{c}Crometer Inc., Hemet, California). During each irrigation event, 24.7 cm ha^{-1} of water was applied at 11.3 L min^{-1} $furrow^{-1}$. Agronomic practices outside of irrigation scheduling were conducted according to Mississippi State University Extension Service recommendations for regional producers (Catchot 2017; Bond et al. 2017).

Sample Parameters

The center two rows of each plot were mechanically harvested at physiological maturity and yields were determined with a calibrated yield monitor (Ag Leader Technology, Ames, Iowa). Irrigation water use efficiency was calculated as described by Vories et al. (2005):

$$IWUE = \frac{Y}{IWA}$$

where IWUE is irrigation water use efficiency (kg/ha-mm), Y is soybean grain yield (kg/ha), and IWA is irrigation water applied (ha-mm). One-meter sections were harvested from each plot to determine plant height, number of main-stem nodes, and pods at physiological maturity.

Economic Analysis

The model used to estimate irrigation costs in this research incorporates irrigation enterprise budgets developed utilizing the Mississippi State University Budget Generator. The model develops estimates of total receipts, total direct expenses, total fixed expenses, total specified expenses, and net returns above total specified expenses on a per hectare basis. The cost estimates were adjusted on an annual basis for the 2015, 2016 and 2017 crop years for changes in variable input costs other than diesel prices. Soybean prices were held constant at $10.00 per bushel. Assumptions related to equipment utilized in each enterprise budget are reported in Table 2. The values for purchase price and fuel consumption are based on personal communications with Mississippi Delta region irrigation equipment input and service providers.

Statistical Analysis

Season-long, static kPa thresholds were analyzed separately from the dynamic kPa thresholds. All data were subjected to Analysis of Variance using the GLIMMIX procedure of SAS (Statistical Analytical System Release 9.4; SAS Institute Inc., Cary, North Carolina). An initial analysis was conducted with year, growth stage, and kPa threshold serving as fixed effects and replication within year, replication by growth stage within year, and growth stage within year and kPa threshold serving as random terms. For soybean grain yield, total irrigation water applied, IWUE, and net return above irrigation costs, the F-values were small compared to the growth stage by kPa threshold interactions, so a second analysis was conducted with year serving as a component of error. In the second analysis, growth stage and kPa threshold served as fixed effects, and year, replication within year, year by growth stage, replication by growth stage within year, year by kPa threshold within growth stage, and growth stage within year by kPa threshold served as random terms. Degrees of freedom were estimated using the Kenward-Roger method. Means were separated using the LSMEANS statement. A contrast statement was used to compare the optimum dynamic kPa threshold treatment to the optimum season-long, static kPa threshold treatment to determine differences in net returns above irrigation costs and IWUE. Differences were considered significant for $\alpha=0.05$.

RESULTS

Seasonal Rainfall Amounts

Seasonal rainfall varied by year during the study compared to the 10-year average rainfall (YAR) amounts (Table 3). The 2015 growing season was characterized as hot and dry, and had 13.5%, 22.1%, and 73.7% less rainfall during the months of June, July, and August, respectively, as the 10 YAR. These conditions resulted in water deficits during critical reproductive growth stages of soybean planted in an early planting date and the frequency of irrigation requirements reflect this (Table 4). In contrast, the 2016 and 2017 growing seasons had higher amounts of rainfall than the 10 YAR, with the months of June, July, and August averaging 112%, 32.5%, and 188% more rainfall, respectively, across both years.

Dynamic Threshold Soybean Grain Yield and IWUE

For soybean grain yield, there was a growth stage by kPa threshold interaction ($P = 0.0012$), while for IWUE neither main effects nor interactions were significant ($P = 0.2696$) (Table 5). For soybean grain yield, the interaction occurred at the R5-R6.5 growth stage. During pod fill, a -125 kPa threshold reduced yield 7.2% compared to the -85 kPa threshold.

Dynamic Threshold Net Returns Above Irrigation Costs

Growth stage and kPa threshold interacted to affect net returns above irrigation costs ($P = 0.0412$) (Table 5). The interaction occurred at the R5-R6.5 growth stage, when a -125 kPa threshold reduced net returns 6.6% compared to the -50 kPa threshold.

Dynamic Threshold 1-m Harvest Samples

Growth stage and kPa threshold interacted to affect plant height ($P \leq 0.0001$), total number of nodes ($P \leq 0.0001$), and pods per plant ($P = 0.0059$) (Table 6). For plant height, the interactions occurred at the VN-R2 and R3-R4 growth stages. Plant height was 14.1% greater for the -50 kPa threshold than the -125 kPa threshold at the VN-R2 growth stage. At the R3-R4 growth stage, the -50 kPa threshold had 4.6% and 7.6% taller plants than the -85 and -125 kPa thresholds, respectively.

Total number of nodes was different among kPa thresholds within all growth stages. For the VN-R2 growth stage, the -50 kPa threshold had 9.1% more nodes than the -85 and -125 kPa thresholds. Within the R3-R4 growth stage, the -85 and -125 kPa thresholds had 11.9% more nodes compared to the -50 kPa threshold. Within the R5-R6.5 growth stage, the -85 kPa threshold had 10.9% more nodes than the -125 kPa threshold, and the -50 kPa threshold was not different from either.

For pods per plant, the interactions occurred at R3-R4 and R5-R6.5 growth stages. At the R3-R4 growth stage, the -50 kPa threshold had 10.0% and 22.4% fewer pods per plant than the -85 and -125 kPa thresholds, respectively. Within the R5-R6.5 growth stage, the -50 kPa threshold had 14.4% more pods per plant than the -125 kPa threshold.

Season-long, Static kPa Threshold Soybean Grain Yield, IWUE, and Net Returns Above Irrigation Costs

Kilopascal threshold affected soybean grain yield and IWUE ($P \leq 0.0001$); however, kPa threshold did not affect net returns above irrigation costs ($P = 0.0537$) (Table 7). Soybean grain yield was 11.6% greater for irrigated than for nonirrigated treatments, yet IWUE for the -50 kPa threshold was 2.9-fold less than the -85 kPa threshold.

Season-long, Static KPa Threshold 1-m Harvest Samples

Kilopascal threshold affected plant height ($P = 0.0002$), total number of nodes ($P \leq 0.0001$), and pods per plant ($P = 0.0054$) (Table 8). For plant height, the -50 kPa threshold was 4.3% taller than the -85 kPa threshold. Total number of nodes and pods per plant were 19.7% and 9.0% fewer, respectively, for the -50 kPa threshold compared to the -85 kPa threshold.

Contrast Analysis of Optimum Dynamic and Season-long, Static Thresholds

For soybean grain yield, net returns above irrigation costs, and IWUE, an analysis was conducted to contrast the dynamic threshold R5-R6.5 growth stage -50 kPa treatment to the season-long, static -85 kPa threshold treatment. Soybean grain yield ($P = 0.1402$) and net returns above irrigation costs ($P = 0.7891$) were not different between the dynamic threshold and the season-long, static threshold. The IWUE ($P = 0.0003$) for the season-long, static -85 kPa threshold was 15.6-fold greater than that of the dynamic R5-R6.5 growth stage -50 kPa threshold.

DISCUSSION

The objective of this research was to determine if soybean grain yield, net returns above irrigation costs, and IWUE are optimized using a static irrigation threshold or if the irrigation threshold should be changed as a function of plant growth stage. Our data indicate that soybean grain yield, net returns above irrigation costs, and IWUE are optimized using a season-long, static -85 kPa threshold. Conversely, Midsouth producers autonomously adopted the practice of initiating irrigation during early reproductive growth stages to hasten canopy development, increasing the number of nodes, and, theoretically, increase yield.

We theorized that soybean grain yield, net returns above irrigation costs, IWUE, and canopy development would be optimized by reducing the threshold to -50 kPa at specific plant growth stages. Relative to the season-long, static -85 kPa threshold, reducing the threshold to -50 kPa did increase total number of nodes, but did not affect soybean grain yield or net returns above irrigation costs at any growth stage. However, reducing the threshold to -50 kPa decreased the IWUE by at least 6.7-fold relative to the season-long, static -85 kPa threshold.

Another hypothesis was that increasing thresholds to -125 kPa at specific growth stages would improve IWUE while maintaining net returns above irrigation costs. When the threshold went to -125 kPa during pod fill, yield and net returns decreased relative to the season-long, static -85 kPa threshold, which is consistent with the literature (Specht et al. 1989; Westgate and Peterson 1993; Foroud et al. 1993; Stegman et al. 1990). The maximum value for this treatment was -132, -102, and -126 kPa during 2015, 2016, and 2017 respectively. These maximum values occurred annually during the mid to late R5 growth stage, and were maintained for approximately 4 days. These data indicate that allowing threshold values to exceed -100 kPa for 4 or more days during R5-R6.5 growth stage reduces net returns above irrigation costs by at least \$103.29 ha^1 relative to the season-long, static -85 kPa threshold.

Unfortunately, based upon our data, we cannot recommend increasing kPa threshold during VN-R4 growth stages. Others have noted that water-deficit stress occurring during early pod development can lead to an increased rate of pod abortion and significant yield reductions (Westgate and Peterson 1993; Liu et al. 2003; Brown et al. 1985; Frederick et al. 1990; Smiciklas et al. 1992). However, the maximum values during the R1-R4 growth stages were -64, -76, and -52 kPa during 2015, 2016, and 2017, respectively. These low values are attributed to timely planting, which coincides with previous research that has shown planting date plays a key role in drought avoidance (Heatherly et al., 1998). Future research is needed to determine if kPa threshold can be increased during the early reproductive stages.

CONCLUSION

The objective of this research was to determine if soybean grain yield, net returns above irrigation costs, and IWUE are optimized using a static irrigation threshold or if the irrigation threshold should be changed as a function of plant growth stage. Our data indicate that soybean grain yield, net returns above irrigation costs, and IWUE are optimized using a season-long, static -85 kPa threshold**.** Moreover, prior research conducted at the farm scale encompassing approximately 23,000 km^2 showed that -85 to -100 kPa thresholds utilized season long did not adversely affect soybean grain yield or net returns above irrigation costs on soil textures ranging from silt loam to clay (Bryant et al., 2017). Overall, results from this research indicate that soybean producers in the Midsouth and other regions that irrigate using lay-flat poly-ethylene tubing can adopt a static -85 kPa soil moisture sensor threshold for early-planted soybean without adversely affecting yield or on-farm profitability, while concurrently decreasing the demand on depleted groundwater resources.

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Table 1. Kilopascal thresholds utilized for dynamic and season-long, static treatments for a study conducted in Stoneville, MS from 2015 through 2017.

	Growth Stage						
Treatment	**VN**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**
VN-R2 -50	-50	-50	-50	-75	-75	-75	-75
VN-R2 -85	-85	-85	-85	-75	-75	-75	-75
VN-R2 -125	-125	-125	-125	-75	-75	-75	-75
R3-R4 -50	-75	-75	-75	-50	-50	-75	-75
R3-R4 -85	-75	-75	-75	-85	-85	-75	-75
R3-R4 -125	-75	-75	-75	-125	-125	-75	-75
R5-R6 -50	-75	-75	-75	-75	-75	-50	-50
R5-R6 -85	-75	-75	-75	-75	-75	-85	-85
R5-R6 -125	-75	-75	-75	-75	-75	-125	-125
Season -50	-50	-50	-50	-50	-50	-50	-50
Season -85	-85	-85	-85	-85	-85	-85	-85
Non-irrigated	-	-	-	-	-	-	-

Table 2. Summary of estimated costs per hectare for full-season soybean irrigated with roll-out pipe, 65-hectare system, for the Delta area, Mississippi, 2018.

Item	Unit	Price	Quantity	Amount
Direct Expenses		$/ha		$/ha
Irrigation Supplies	hectare	20.38	1.00	20.38
Soil Moisture Sensors	hectare	0.64	1.00	0.64
Irrigation Labor	hour	22.38	0.8954	8.15
Operator Labor	hour	33.37	0.1939	2.62
Diesel Fuel	gal	4.45	19.90	35.86
Repair and Maintenance	hectare	18.48	1.00	18.48
Interest on Op. Cap.	hectare	1.36	1.00	1.36
Total Direct Expenses				**87.49**

Table 3. Rainfall (cm) amounts for March through October in 2015, 2016, 2017, and 10 year average at Stoneville, MS.

Month	2015	2016	2017	10 Year Average
March	18.57	46.91	7.57	14.22
April	16.08	10.95	16.84	14.22
May	17.68	8.28	12.40	13.11
June	6.53	12.85	19.28	7.54
July	8.05	16.59	10.95	10.34
August	1.85	13.92	27.28	7.06
September	2.01	0.86	4.29	9.53
October	13.94	0.51	0.56	13.49
Total	**84.71**	**110.87**	**96.62**	**89.51**

Table 4. Irrigation water applied (cm ha^{-1}) at specific growth stages by year for a study conducted in Stoneville, MS from 2015 through 2017.

2015

	Growth Stage							
Treatment	**VN**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**Total**
VN-R2 -50			24.7			49.4	49.4	**123.5**
VN-R2 -85				24.7		24.7	49.4	**98.8**
VN-R2 -125						24.7	49.4	**74.1**
R3-R4 -50			24.7			24.7	24.7	**74.1**
R3-R4 -85							49.4	**49.4**
R3-R4 -125						24.7	24.7	**49.4**
R5-R6 -50						98.8	74.1	**172.9**
R5-R6 -85				24.7		74.1	74.1	**172.9**
R5-R6 -125				24.7			49.4	**74.1**
Season -50			24.7			98.8	74.1	**197.6**
Season -85						24.7	49.4	**74.1**

2016

	Growth Stage							
Treatment	**VN**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**Total**
VN-R2 -50			24.7		24.7	49.4	24.7	**123.5**
VN-R2 -85				24.7		24.7		**49.4**
VN-R2 -125					24.7	24.7	24.7	**74.1**
R3-R4 -50				24.7		49.4		**74.1**
R3-R4 -85				24.7	24.7	49.4	24.7	**123.5**
R3-R4 -125			24.7			49.4	24.7	**98.8**
R5-R6 -50				24.7	24.7	49.4	24.7	**123.5**
R5-R6 -85			24.7	24.7		49.4		**98.8**
R5-R6 -125			24.7	24.7	24.7			**74.1**
Season -50			24.7	24.7	24.7	49.4	24.7	**148.2**
Season -85			24.7		24.7	49.4	24.7	**123.5**

2017

	Growth Stage							
Treatment	**VN**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**Total**
VN-R2 -50							24.7	**24.7**
VN-R2 -85								
VN-R2 -125							24.7	**24.7**
R3-R4 -50				24.7			24.7	**49.4**
R3-R4 -85							24.7	**24.7**
R3-R4 -125								
R5-R6 -50						74.1	24.7	**98.8**
R5-R6 -85								
R5-R6 -125							24.7	**24.7**
Season -50				24.7		74.1	24.7	**123.5**
Season -85							24.7	**24.7**

Table 5. Mean±SEM soybean grain yield (kg ha^{-1}), irrigation water use efficiency (kg ha^{-1} mm^{-1}), and net returns above irrigation costs (\$ ha^{-1}) for a study conducted in Stoneville, MS from 2015 through 2017.

Growth Stage	kPa[1] Threshold	Yield	IWUE	Net Return
VN-R2	50	4006(124) ab	3.8(0.1)	1213.33(50.30) a
VN-R2	85	4061(78) ab	6.7(1.0)	1259.33(35.76) a
VN-R2	125	4037(139) ab	5.7(0.2)	1244.96(55.52) a
R3-R4	50	3921(134) bc	6.8(0.3)	1202.51(50.38) ab
R3-R4	85	3953(115) abc	5.7(0.8)	1207.32(42.11) ab
R3-R4	125	4038(131) ab	6.3(0.6)	1244.89(48.12) a
R5-R6	50	4158(104) a	2.9(0.3)	1222.29(45.67) a
R5-R6	85	4011(116) ab	3.5(0.4)	1204.75(51.25) ab
R5-R6	125	3741(126) c	5.3(0.3)	1141.60(49.28) b

[1]Kilopascal
*Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

Table 6. Mean±SEM plant height (cm), total number of nodes, and number of pods per plant for a study conducted in Stoneville, MS from 2015 through 2017.

Growth Stage	kPa[1] Threshold	Height	Nodes	Pods
VN-R2	50	78.4(0.6) b	60.5(1.5) a	159.1(5.0) abc
VN-R2	85	77.8(0.6) b	55.0(1.7) bcd	153.0(5.1) bc
VN-R2	125	67.3(0.8) d	54.9(1.8) bcd	150.2(5.4) cd
R3-R4	50	81.1(0.5) a	51.1(1.5) cd	142.6(4.9) cd
R3-R4	85	77.4(0.5) b	60.7(1.7) a	156.9(4.6) abc
R3-R4	125	74.9(1.5) c	57.6(2.2) ab	174.5(7.7) a
R5-R6	50	75.7(0.4) bc	51.7(1.5) bcd	155.7(4.9) abc
R5-R6	85	78.1(0.6) b	55.1(1.4) abc	169.2(4.5) ab
R5-R6	125	76.1(0.4) bc	49.1(1.7) d	133.3(4.6) d

[1]Kilopascal
*Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

Table 7. Mean±SEM soybean grain yield (kg ha^{-1}), irrigation water use efficiency (kg ha^{-1} mm^{-1}), and net returns above irrigation costs (\$ ha^{-1}) for season-long, static kPa threshold treatments for a study conducted in Stoneville, MS from 2015 through 2017.

KPa[1] Threshold	Yield	IWUE[2]	Net Return
50	4,195(99)a	17.2(1.1) b	1198.85(50.06) b
85	4,010(93) a	45.3(10.5) a	1219.06(35.78) ab
Non-irrigated	3,627(101) b	-	1298.25(38.82) a

[1]Kilopascal
[2]Irrigation Water Use Efficiency
*Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

Table 8. Mean±SEM soybean plant height (cm), total number of nodes, and number of pods per plant for season-long, static kPa threshold treatments for a study conducted in Stoneville, MS from 2015 through 2017.

KPa[1] Threshold	Height	Nodes	Pods
50	79.0(0.9) a	59.1(1.9) b	171.4(4.5) b
85	75.3(0.9) b	73.6(1.9) a	188.6(5.6) a
Non-irrigated	78.5(0.4) a	56.5(1.2) b	151.9(3.6) c

[1]Kilopascal
*Values in a column followed by the same letter are not significantly different at $P \leq 0.05$