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FINAL REPORT

Title: Furrow diking as a Midsouthern US irrigation strategy: Soybean (*Glycine max*) grain yield, irrigation water use efficiency, and net return above furrow diking costs

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EXECUTIVE SUMMARY

Best management practices (BMP) to improve irrigation efficiency and rainfall capture are needed in the Midsouthern US to ease overdrafts from the Mississippi River Valley Alluvial Aquifer (MRVAA). One potential BMP is furrow diking (FD), where tillage is used to create small basins within the furrow to capture water from rainfall and irrigation.

The objective of this research was to quantify the efficacy of FD in a soybean production system through its impacts on soybean grain yield, irrigation water use efficiency (IWUE), and net returns. Two studies were conducted to evaluate FD in irrigated and rainfed systems. Treatments included FD and non-diked (control) in a randomized complete block design with six replications.

Furrow diking had no impact on soybean grain yield in either irrigated or rainfed environments ($P \geq 0.2426$; Tables 1 & 2).

Similar yields were maintained in the FD system when 25% less water was applied, increasing the irrigation water use efficiency by 28% ($P < .0001$).

FD did not significantly affect total revenue or net returns above FD costs ($P \geq 0.2375$; Table 3).

These results indicate FD is a possible BMP for increasing Midsouth irrigation efficiency and decreasing aquifer withdrawals.

Table 1. Yield components and soybean grain yield from a furrow-irrigated, furrow diking study conducted in Stoneville, MS in 2011 and 2012.

Treatment	PMR*	PSM†	PPP‡	WPS§	W1KS‖	Yield
				------------g------------		kg ha^{-1}
Furrow Dike	24#	1060.25	46.26	542.07	157.36	3265.21
Non-Furrow Dike	23	1025.58	45.92	525.57	157.20	3360.70

*PMR = plant m row^{-1}
†PSM = pods m^{-2};
‡PPP = pods $plant^{-1}$;
§WPS = weight of pods and seed;
‖W1KS = weight of 1,000 seed.
#Numbers within a column without letters are not different at $\alpha = 0.05$

Table 2. Yield components and soybean (*Glycine max*) grain yield from a rainfed furrow diking study conducted in Stoneville, MS in 2011 and 2012.

Treatment	PMR*	PSM†	PPP‡	WPS§ (g)	W1KS‖ (g)	Yield (kg ha^{-1}
Furrow Dike	26	1066.25	43.00	511.32 A#	145.71	2227.23
Non-Furrow Dike	27	1017.50	38.83	467.01 B	144.06	2299.23

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#Numbers within a column with different letters are different at $\alpha = 0.05$

Table 3. Total irrigation lifting costs, total revenue, and net returns above furrow diking costs for irrigated and dry-land *soybean (Glycine max) furrow diking studies conducted in Stoneville, MS in 2011 and 2012.*

Study	Treatment	Irrigation Lifting Costs	Total Revenue	Net Returns
		-------------------------*$ ha^{-1}$*------------------------		
Irrigated	Furrow Dike	74.75	1632.60	1535.31
	Non-Furrow Dike	100.44	1680.35	1557.70
Rainfed	Furrow Dike	—	1113.61	1091.07
	Non-Furrow Dike	—	1149.61	1127.40

FURROW DIKING

ABSTRACT

Best management practices (BMP) to improve irrigation efficiency and rainfall capture are needed in the Midsouthern US to ease overdrafts from the Mississippi River Valley Alluvial Aquifer (MRVAA). One potential BMP is furrow diking (FD), where tillage is used to create small basins within the furrow to capture water from rainfall and irrigation.

The objective of this research was to quantify the efficacy of FD in a soybean production system through its impacts on soybean grain yield, irrigation water use efficiency (IWUE), and net returns. Two studies were conducted to evaluate FD in irrigated and rainfed systems. Treatments included FD and non-diked (control) in a randomized complete block design with six replications. Furrow diking had no impact on soybean grain yield in either irrigated or rainfed environments ($P \geq 0.2426$). Similar yields were maintained in the FD system when 25% less water was applied, increasing the irrigation water use efficiency by 28% ($P < .0001$). FD did not significantly affect total revenue or net returns above FD costs ($P \geq 0.2375$). These data indicate FD is a possible BMP for increasing Midsouth irrigation efficiency and decreasing aquifer withdrawals.

Key words: water conservation; furrow irrigation; depressional storage; Mississippi River Valley Alluvial Aquifer

The ability to irrigate row crops from the Mississippi River Valley Alluvial Aquifer (MRVAA) is crucial to the sustainability of soybean production in the Midsouthern US**.** However, groundwater is not an unlimited resource, even in humid regions, and must be prudently managed to ensure its continued availability.

In the Mississippi Delta of the Midsouth region of the US, the primary irrigation source is the MRVAA (Massey et al. 2017). The sole reliance of irrigators on the MRVAA has led to rates of discharge greater than rates of recharge (Guzman et al. 2014). The long-term, average, weighted withdrawal from the MRVAA in the Delta region of Mississippi is 4,200 m^3 ha^{-1} $season^{-1}$ across all crops and 2,800 m^3 ha^{-1} $season^{-1}$ for soybean (Massey et al. 2017).

With the adoption of high efficiency irrigation systems, such as sub-surface drip and overhead sprinkler, it is surprising to many outside of the Midsouth that a system as inefficient as furrow irrigation is still widely practiced. Irrigation systems within the Midsouth are predominantly furrow (Heatherly and Ray 2007). Furrow irrigation systems are well-suited to the Midsouth due to nearly uniform landforms and the implementation of precision land forming to aid in irrigation application uniformity (Massey et al. 2017). Until producers in the Midsouth transition to efficient delivery systems, strategies to increase the efficiency of furrow irrigation are required.

One proposed method to increase the application efficiency of furrow irrigation is furrow diking (FD). Furrow diking is a tillage operation performed before, with, or after planting, and creates depressions within the furrow and dikes or dams across the furrow to aid in water retention and infiltration (Nuti et al. 2009). The goal of FD is to decrease runoff from agricultural lands through impoundment of rainfall and irrigation water, thereby increasing time available for infiltration and soil profile wetting. Arid and semi-arid regions most typically see implementation of FD on a commercial level (Jones and Baumhardt 2003), with some research being conducted in the Southeastern US in recent years (Nuti et al. 2009; Truman and Nuti 2010).

To date there is a paucity of data regarding the viability of FD in Midsouth production systems and, more specifically, in furrow-irrigated soybeans. The lack of research on FD is especially confounding since this tillage strategy is prescribed as a USDA-NRCS approved best management practice (BMP).

The objectives of this research were to implement FD in a typical Midsouth soybean production system under irrigated and rainfed environments. The efficacy of FD was determined based on its ability to maintain or improve yield, irrigation water use efficiency (IWUE), and economic parameters relative to a non-diked (ND) system.

MATERIALS AND METHODS

In 2011 and 2012, rainfed and furrow irrigation studies were conducted on a Dundee silt loam with 0-2% slope at the USDA-ARS Crop Production Systems Research Unit farm near Stoneville, MS. Treatments consisted of FD and ND (control) arranged in a randomized complete block (n=6). Plots were 12 rows wide by 37 m long where rows 1, 2, 3, 10, 11, and 12 were border and rows 4, 5, 7, and 8 were for two row harvest samples.

Tillage consisted of disking and formation of 102-cm-wide raised seedbeds in the fall followed by one pass with a reel and harrow seed bed conditioner. Soybean variety Armor© 4744 (Armor Seed, LLC, Jonesboro, AR) was planted at 345,935 seeds ha^{-1} on 15 April and 10 April in 2011 and 2012, respectively. Furrow diking was completed in the spring on non-traffic rows. Soybeans were mechanically harvested at physiological maturity using a 2-row plot combine and weights and moisture content were recorded using a calibrated yield monitor. All crop management factors were conducted according to Mississippi State University Extension guidelines.

Parameters measured to monitor soybean growth and development and aid in explaining potential yield differences between treatments included plants m^{-1} row, pods m^{-2}, pods $plant^{-1}$, weight of pods and seeds (g m^{-2}), and weight of 1,000 seeds (g). Other measured parameters included yield (kg ha^{-1}), irrigation water applied (IWA, ha-mm), and IWUE. Irrigation water use efficiency calculations were performed using procedures described by Vories et al. (2005):

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

where IWUE is irrigation water use efficiency (kg ha-mm^{-1}), Y is soybean grain yield (kg ha^{-1}), and IWA is irrigation water applied (ha-mm).

Irrigation events were scheduled using FAO-56 as described by Allen et al. (1998) and initiated when a 20.6-mm soil deficit occurred. Water was lifted from groundwater sources and delivered using lay-flat polyethylene tubing. The well outlet was fitted with a McCrometer flow tube with attached McPropeller bolt on saddle flowmeter (McCrometer Inc., Hemet, CA) to measure water flow rates and irrigation water volume applied. Irrigation rates were 75% and 100% of evapotranspiration (ET) replacement for FD and ND, respectively. Since this soil type is prone to surface sealing/crusting, an infiltration volume equaling 50% of applied water was assumed; therefore, 30. and 41.2 ha-mm were applied to FD and ND, respectively, to satisfy desired ET replacements. Irrigation water was applied to non-traffic furrows in both FD and ND treatments.

Economic analysis was conducted to determine net returns above FD costs. Direct costs for FD include purchase and operation of the implement along with associated irrigation setup and water lifting costs. It was assumed the FD implement would be connected to the planter and furrow dikes would be created simultaneously with planting. Partial budgets were developed using Mississippi State University Delta planning budgets for 2012 and 2013 (Mississippi State University 2012, 2013) and the Mississippi State University budget generator. Price of the FD implement was obtained from Sam Stevens Implement (Sam Stevens Implement Co. Lamesa, TX; Personal communication with Sammy Stevens, 08 MAR 2018). Costs for water lifting and soybean prices were averaged across years (Table 1).

Results were analyzed using the MIXED procedure in SAS (Statistical Analytical System Release 9.4; SAS Institute Inc. Cary, North Carolina) and means were separated using Fisher's Protected LSD at $\alpha \leq 0.05$. Random statements included rep, rep x year, and rep within year. While years were different for some yield components, treatments behaved the same within years; therefore, results presented are averaged across years.

RESULTS AND DISCUSSION

Soybean grain yield was not different in either the irrigated or rainfed studies when FD was implemented ($P \geq 0.2426$; Tables 1 and 2). Furrow diking had no influence on any yield parameters in the irrigated study ($P = 0.6063$). However, FD increased the weight of pods and seeds in the rainfed study ($P = 0.0484$), but no other yield parameters were affected ($P \geq 0.0512$). These data are in agreement with others who noted that FD had no effect on crop yield under sprinkler irrigation (Nuti et al. 2009; Baumhardt et al. 1993). Conversely, others reported that FD increased crop yields under irrigation (Nuti et al. 2009; Jones and Clark 1987). Nuti et al. (2011) suggested that differences in FD effects on yield across years were attributable to rainfall patterns. Differences in crop yield where not observed when years were either wet or dry, but FD increased soybean grain yield in years with moderate rainfall.

Furrow diking affected IWUE ($P < .0001$). Pooled over years, FD increased IWUE 28% relative to the control. Others have reported that FD increased IWUE 110% to 213% relative to ND (Jones and Clark 1987). Most assume that increases in IWUE come at the expense of yield, and subsequently, net returns; however, this study indicates that 25% less water can be applied to FD systems while maintaining yield. The potential to reduce irrigation application volume while maintaining yield and net returns is promising to the Midsouth where agricultural withdrawal from the MRVAA is unsustainable.

Total revenue and net returns above FD costs were not different between treatments in either the irrigated or rainfed environments ($P \geq 0.2375$; Table 4). Similarly, a three-year cotton study in Georgia also reported no difference in net returns between FD and ND treatments (Nuti et al.

2009). These data indicate that costs associated with the purchase and operation of the FD implement are offset by savings due to reduced irrigation lifting requirements.

CONCLUSIONS

The objective of this research was to quantify the effect of furrow diking (FD) on soybean grain yield, IWUE, and net return. These results indicate that FD improves IWUE by 28% with no adverse effect on soybean grain yield or net returns above FD costs. Furrow diking should be a recommended BMP to improve furrow irrigation efficiency and ease withdrawals from the MRVAA.

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Table 1. Soybean grain price, estimated purchase price, and operating costs for inputs used in partial budget analysis of a furrow-irrigated and rainfed furrow diking study conducted in Stoneville, MS in 2011 and 2012.

Test	Costs	Price ($)
Irrigated	FD* Implement ($ row unit^{-1})	350.00
	Planting with FD ($ ha^{-1})	22.54
	Planting without FD ($ ha^{-1})	22.21
	Irrigation Costs FD ($ ha^{-1})	74.75
	Irrigation Costs ND ($ ha^{-1})	100.44
	Soybean Price ($ kg^{-1})	0.50
Rainfed	FD Implement ($ row unit^{-1})	350.00
	Planting with FD ($ ha^{-1})	22.54
	Planting without FD ($ ha^{-1})	22.21
	Soybean Price ($ kg^{-1})	0.50

* FD = Furrow Diking

Table 2. Yield components and soybean grain yield from a furrow-irrigated, furrow diking study conducted in Stoneville, MS in 2011 and 2012.

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Table 4. Total irrigation lifting costs, total revenue, and net returns above furrow diking costs for irrigated and dry-land *soybean (Glycine max) furrow diking studies conducted in Stoneville, MS in 2011 and 2012.*

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