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Furrow Diking as a Mid-Southern USA Irrigation Strategy: Soybean Grain Yield, Irrigation Water Use Efficiency, and Net Returns above Furrow Diking Costs

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Abstract

Best management practices (BMP) to improve irrigation efficiency and rainfall capture are needed in the Mid-Southern USA to ease overdrafts from the Mississippi River Valley Alluvial Aquifer (MRVAA). One potential BMP is furrow diking (FD), wherein 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 effect of FD on soybean grain yield, IWUE, and economic analysis under both irrigated and rainfed environments. 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 ($P > 0.05$). Similar yields were maintained in the FD system when 25% less water was applied, increasing the irrigation water use efficiency by 28% ($P < 0.0001$). No effect of FD was observed on total revenue or net returns above FD costs ($P > 0.05$). These data indicate FD is a possible BMP for increasing irrigation efficiency and decreasing aquifer withdrawals in Mid-Southern USA soybean production.

The ability to irrigate row crops from the Mississippi River Valley Alluvial Aquifer (MRVAA) is crucial to the sustainability of soybean (*Glycine max*) production in the Mid-Southern USA. However, groundwater is a limited resource; therefore, even in humid regions groundwater must be prudently managed to ensure its continued viability. In the Delta region of Mississippi in the Mid-Southern USA, the primary irrigation source is the MRVAA (Massey et al., 2017). The sole reliance of irrigators on the MRVAA has led to rates of decline greater than rates of recharge (Guzman et al., 2014). The long-term, average, weighted withdrawal from the MRVAA in the Delta region of Mississippi, USA is 60,000 ft^3/acre/season across all crops and 40,000 ft^3/acre/season for soybean (Massey et al., 2017).

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Core Ideas

- Furrow diking increases soybean irrigation water use efficiency.
- Furrow diking should be a Mid-Southern USA BMP.
- Furrow diking reduces Mississippi River Valley Alluvial Aquifer overdrafts.

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Conversions: For unit conversions relevant to this article, see Table A.

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.405	acre	hectare, ha
0.304	foot, ft	meter, m
9.29×10^{-2}	square foot, sq ft	square meter, sq m
2.83×10^{-2}	cubic foot, cu ft	cubic meter, cu m
28.4	ounce (avdp), oz	gram, g
67.19	60-lb bushel per acre, bu/acre	kilogram per hectare, kg/ha
1.64×10^{5}	cubic inch, cu inch	cubic meter, cu m

With the adoption of irrigation systems with increased efficiency, such as subsurface drip and overhead sprinkler with efficiencies ranging between 95 and 85% (Lamm and Trooien, 2003), it is surprising to many, outside of the Mid-Southern USA, that a system as inefficient as furrow irrigation, with an efficiency of approximately 65% (Lamm and Trooien, 2003), is still widely practiced. Irrigation systems within the Mid-Southern USA are predominantly furrow (Heatherly and Ray, 2007). Furrow irrigation systems are well suited to the Mid-Southern USA, 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 Mid-Southern USA 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, which creates depressions within the furrow and dikes or dams across the furrow to aid in water retention and infiltration (Nuti et al., 2009). The overarching 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 semiarid regions most typically see implementation of FD on a commercial level (Jones and Baumhardt, 2003), with some research being conducted in the Southeast USA, 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 Mid-Southern USA production systems and, more specifically, in furrow-irrigated soybeans. The lack of research on FD is especially confounding in that this tillage strategy is prescribed as a USDA-NRCS approved best management practice (BMP). The objective of this research was to quantify the effect of FD on soybean grain yield, IWUE, and economic analysis under both irrigated and rainfed environments.

Site Description and Field Procedures

In 2011 and 2012, rainfed and furrow irrigation studies were conducted on a Dundee silt loam (Fine-silty, mixed, active, thermic Typic Endoaqualfs) 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 120 ft long where rows 1, 2, 3, 6, 9, 10, 11, and 12 were border and rows 4, 5, 7, and 8 were for two row harvest samples, which were summed to provide plot yield.

Tillage consisted of disking and formation of 40-inch-wide raised seed beds in the fall followed by one pass with a reel and harrow seed bed conditioner and soybean planting in the spring. Soybean variety Armor 4744 (Armor Seed, LLC, Jonesboro, AR) was planted at 140,000 seeds/acre on 15 April and 10 April for 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. Soybean harvest occurred on 9 September and 14 September for 2011 and 2012, respectively. All crop management factors were maintained according to Mississippi State University Extension guidelines.

Irrigation

Irrigation events were scheduled using FAO-56 as described by Allen et al. (1998) and initiated when a 2-inch soil deficit occurred. As FAO-56 is a water-balance approach to calculating soil moisture deficits, based on known environmental parameters, crop growth stage, and a calculated reference ET value, irrigation events were scheduled simultaneously for both treatments. Irrigation rates were 75 and 100% evapotranspiration (ET) replacement for FD and ND, respectively. As this soil type is prone to surface sealing/crusting an infiltration volume equaling 50% of applied water was assumed; therefore, 3 and 4 acre-inches were applied to FD and ND, respectively, to satisfy desired ET replacements. At a 2-inch soil deficit and an assumed infiltration volume equaling 50% of applied water, these irrigation rates will provide 1.5 and 2 acre-inches of soil moisture (i.e., 75 and 100% ET replacement) in the FD and ND treatments, respectively. Water was lifted from groundwater sources and delivered via lay-flat polyethylene tubing (Delta Plastics, Little Rock, AR). 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 water was applied to non-traffic furrows in both FD and ND treatments.

Table 1. Soybean (*Glycine max*) grain price, estimated purchase price, and operating costs for inputs used in partial budget analysis of furrow-irrigated and rainfed furrow diking studies conducted in Stoneville, MS in 2011 and 2012.

Study	Inputs	Revenue	Price		
			$/row unit	$/acre	$/lb
Irrigated					
	FD† implement		350.00		
	Planting with FD			9.12	
	Planting without FD			8.99	
	Irrigation costs FD			30.25	
	Irrigation costs ND‡			40.65	
		Soybean price			1.10
Rainfed					
	FD implement		350.00		
	Planting with FD			9.12	
	Planting without FD			8.99	
		Soybean price			1.10

† FD = Furrow diking.

‡ ND = Non-furrow dike.

Table 2. Rainfall amounts for March through September and the 30-year average for all years of furrow-irrigated and rainfed furrow diking studies conducted in Stoneville, MS in 2011 and 2012.

Month	Rainfall totals		
	2011	2012	30-year average
	inches		
March	2.79	5.94	4.54
April	6.31	4.19	4.81
May	2.76	2.03	4.80
June	1.58	6.39	3.69
July	1.96	4.57	3.65
August	2.41	4.29	2.49
September	3.96	3.26	3.72
Total	21.77	30.67	27.7

Measured Parameters

Soybean growth and development was monitored by sampling plants/row ft, pods/ft^2, pods/plant, weight of pods and seeds (oz/ft^2), and weight of 1000 seeds (oz), these measurements aid in explaining any potential differences in yield. Other measured parameters included yield (bu/acre), irrigation water applied (IWA, acre-in.), and IWUE. Irrigation water use efficiency calculations were performed using procedures described by Vories et al. (2005):

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

where IWUE is irrigation water use efficiency (bu/acre-in.), Y is soybean grain yield (bu/acre), and IWA is irrigation water applied (acre-in.).

Economic Analysis

Economic analysis was conducted to determine net returns above FD specified costs using a partial budgeting technique (Kay et al., 2015). Specified costs for FD include purchase and operation of the implement along with associated irrigation setup and water lifting costs. Price of the FD implement in this study was $350 per row unit that was obtained from Sam Stevens Implement (Sam Stevens Implement Co. Lamesa, TX; S. Stevens, personal communication, 2018). Based on FD practices in the Texas High Plains, 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 data taken from Mississippi State University Delta planning budgets for 2012 and 2013 (Mississippi State University, 2011, 2012) and the Mississippi State University budget generator. These partial budgets were based on the assumption of the use of a 12-row 38-inch planter. For this implement, the increase in costs due to addition of the FD equipment was estimated to be $0.13 per acre. The increased costs per acre was composed of a $0.05 increase in repair and maintenance and a $0.08 increase in capital recovery costs. Assumptions related to equipment utilized in partial budget analysis are reported in Table 1 along with costs of water lifting and soybean prices, which were averaged across years.

Statistical Analysis

Results were analyzed using the MIXED procedure in SAS (9.4; SAS Inst. Inc. Cary, NC) and means were separated using Fisher's Protected LSD at $\alpha \leq 0.05$. Random statements included rep, rep by 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.

Seasonal Rainfall

Compared to the 30-year average rainfall amounts, seasonal rainfall varied by year during the course of the study (Table 2). Rainfall during the 2011 growing season averaged 21.4% less rainfall than the 30-year average rainfall total. The 2011 growing season is therefore classified as hot and dry and resulted in water deficits during all growth stages. Conversely, the 2012 growing season averaged 10.7% more rainfall than the 30-year average rainfall total and is classified as a wet season. However, supplemental irrigation was still required in the irrigated trial during the 2012 growing season.

Soybean Grain Yield

Implementation of FD had no effect on soybean grain yield in either the irrigated or rainfed study ($P \geq 0.2426$; Table 3). 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;

Table 3. Yield components, soybean (*Glycine max*) grain yield, and irrigation water use efficiency (IWUE) from furrow-irrigated and rainfed furrow diking studies conducted in Stoneville, MS in 2011 and 2012.

Study	Treatment	PFR†	PSF‡	PPP§	WPS¶	W1KS#	Yield	IWUE
					oz	oz	bu/acre	bu/acre-inch
Irrigated								
	Furrow dike	7 A††	98.50 A	46.26 A	19.12 A	5.55 A	54.62 A	8.40 A
	Non-furrow dike	7 A	95.33 A	45.92 A	18.54 A	5.55 A	56.36 A	6.55 B
Rainfed								
	Furrow dike	8 A	99.06 A	42.99 A	18.04 A	5.14 A	37.61 A	
	Non-furrow dike	8 A	94.53 A	38.83 A	16.47 B	5.08 A	38.59 A	

† PFR = plants/foot of row.

‡ PSF = pods/ft^2.

§ PPP = pods/plant.

¶ WPS = weight of pods and seed.

W1KS = weight of 1000 seed.

†† Numbers within a column and study followed by the same letter are not different at $\alpha = 0.05$.

Jones and Clark, 1987). Nuti et al. (2011) suggested that differences in FD effects on yield across years were attributed to rainfall patterns. Differences in crop yield were not observed when years were either wet or dry, but FD increased soybean grain yield in years with moderate rainfall (Nuti et al., 2011).

Irrigation Water Use Efficiency

Furrow diking had an effect on IWUE ($P < 0.0001$). Pooled over years, FD increased IWUE 28% relative to control (Table 3). 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 Mid-Southern USA, where agricultural withdrawal from the MRVAA is unsustainable.

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

Study	Treatment	TWA†	ILC‡	TR§	NR¶
		acre-inch	———— $/acre	————	
Irrigated	FD#	11.5	30.25	660.70	621.33 A‡‡
	ND††	15.5	40.65	680.03	630.39 A
Rainfed	FD			450.67	441.55 A
	ND			465.24	456.25 A

† TWA = Total water applied averaged across years. Treatments scheduled simultaneously for all irrigation events and 25% less water was applied to the FD treatment.

‡ ILC = Irrigation lifting costs.

§ TR = Total revenue.

¶ NR = Net returns above furrow diking costs.

FD = Furrow dike.

†† ND = Non-furrow dike.

‡‡ Numbers in a column followed by the same letter are not different at the $\alpha = 0.05$ level of significance.

Net Returns

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 3-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 purchase and operation of the FD implement are offset by savings due to reduced irrigation lifting requirements.

Conclusion

The objective of this research was to quantify the effect of FD on soybean grain yield, IWUE, and economic analysis under both irrigated and rainfed environments. Our data indicate that FD improves IWUE by 28% with no adverse effect on soybean grain yield or net returns above FD costs. In Mid-Southern USA soybean production, FD should be a recommended BMP to improve furrow irrigation efficiency and ease withdrawals from the MRVAA.

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