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Profitability of twin-row planting and skip-row irrigation in a humid climate

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Abstract

We assessed the potential profitability of twin-row (TR) planting geometry as a water productivity-enhancing practice and of skip-row irrigation (SRI) as a water-conserving practice in furrow-irrigated cotton (*Gossypium hirsutum* L.) and soybean (*Glycine max* L.). Data from agronomic experiments carried on Dundee silt loam soils indicate that, on average, TR planting increases profitability by US\$344 ha^{-1} for all-row irrigated (ARI), \$401 ha^{-1} for SRI, and \$334 ha^{-1} for rainfed (RF) cotton. For soybean, the gains were \$178 ha^{-1} for ARI irrigated, \$178 ha^{-1} for SRI, and \$121 ha^{-1} for RF. Converting from ARI to SRI irrigation can conserve 88 mm of irrigation water on average for cotton and 91 mm of irrigation water on average for soybean, while improving cotton profits by \$55–113 ha^{-1}. Soybean growers can expect a reduction in profits from SRI of ∼\$11 ha^{-1}. Incentive payment for soybean growers of ∼\$0.132 mm^{-1} of saved water would compensate farmers for the expected losses of adopting SRI in the Delta of Mississippi.

1 | INTRODUCTION

The Mississippi River Valley Alluvial Aquifer is a lifeline of irrigated agriculture in the Mississippi Delta that is depleting at an unsustainable rate (Quintana-Ashwell et al., 2020; Yasarer et al., 2020). Growing food demand and limited availability of irrigation water exert further pressure on agricultural areas with relatively rich freshwater resources such as the Mississippi Delta (Elliott et al., 2014). Agricultural practices that reduce the rate of groundwater extraction are necessary to preserve the alluvial aquifer. Fortunately, there is growing evidence that important water savings are achievable with relatively minor modifications to existing irrigation and agronomic practices in the Mid-Southern United States (Bryant et al., 2017; Henry & Krutz, 2016; Quintana-Ashwell et al., 2020; Spencer et al., 2019; Wood et al., 2017). Furthermore, it is possible to increase water productivity in areas of falling groundwater levels to allow farmers to profitably conserve water (Molden et al., 2010). Profitability is a fundamental component of sustainable agriculture. Farmers operate in an increasingly risky environment. In addition to more frequent floods and droughts driven by climate change, farmers face increasing input prices and uncertain commodity markets. Available hedging and insurance products add to farming costs and do not always cover the emergent losses. For example, the roughly US\$23.5 billion in Market Facilitation Program payments was intended to compensate farmers for losses due to retaliatory tariffs in 2018 and 2019, but may not cover the long-term farm losses caused by the trade war (Janzen & Hendricks, 2020). Naturally, conservation-inclined farm-

Abbreviations: ARI, all-row irrigation; BMP, best management practice; IPAR, canopy-intercepted active radiation; IWUE, irrigation water use efficiency; RF, rainfed; SR, single-row; SRI, skip-row irrigation; TR, twin-row.

ers need assurances that they can adopt conservation practices profitably (Adams & Kovacs, 2019).

Because the Mississippi River Valley Alluvial Aquifer requires reduced aggregate pumping, agricultural practices that increase the productivity of applied irrigation water (i.e., increased water use efficiency) are required to compensate for reduced water input usage. Practices that improve water productivity can increase profits or reduce risks and would be more likely to be adopted by farmers (Quintana-Ashwell et al., 2020). In this paper, we assess the profitability of a water-saving practice (skip-row irrigation [SRI]) and a water productivity-enhancing practice (twin-row [TR] planting) for furrow-irrigated cotton (*Gossypium hirsutum* L.) and soybean (*Glycine max* L.) based on published data for the Delta region of Mississippi (Pinnamaneni, Annapalli, Reddyl & Fisher, 2020; Pinnamaneni, Anapalli, Reddy, Fisher, & Quintana-Ashwell, 2020).

More than 93% of growers in the Mississippi Delta reported operating irrigated cotton or soybean fields in 2016 (Quintana-Ashwell et al., 2020). Cotton production and its historical, political, and economical importance to the Delta region is well documented from long before "Cotton was King" (Brown, 2011). More than 350,000 t of cotton were harvested from over 287,000 ha in Mississippi in 2019 (USDA-NASS, 2020). Over the years, significant portions of cotton farmland have been converted to soybean production (Pinnamaneni, Anapalli, Reddy, & Fisher, 2020). Soybean is a major cash crop in Mississippi, where over 900,000 ha and 700,000 ha were planted in 2018 and 2019, respectively. Despite ongoing trade wars and severe flooding in the South Delta, 3,200,000 and 2,200,000 t of soybean were produced in 2018 and 2019, respectively (USDA-NASS, 2020).

Core Ideas

- Converting from full- to skip-row irrigation improved risk-return for cotton.
- Skip-row irrigation improved risk-return for twin-row soybean.
- Skip-row irrigation worsened risk-return for single-row soybean.
- Skip-row irrigation costs soybean farmers \$0.132 mm^{-1} of saved water.

1.1 | TR planting geometry

In Mississippi, cotton and soybean are typically planted in a single-row planting geometry (SR) on raised beds with 96-to-102-cm spacing between them (Pinnamaneni, Annapalli, Reddy, & Fisher, 2020; Pinnamaneni, Anapalli, Reddy, Fisher, & Quintana-Ashwell, 2020). The TR planting employs the same bed spacing as SR with the same number of seeds planted in two rows spaced between 18 and 38 cm on the same bed (Smith, Kaur, Orlowski, Mahaffey, et al., 2019). The evidence in the agronomic literature indicates that TR planting has the potential to improve profits for cotton and soybean production (Pinnamaneni, Annapalli, Reddy, & Fisher, 2020; Pinnamaneni, Anapalli, Reddy, Fisher, & Quintana-Ashwell, 2020; Smith, Kaur, Orlowski, Mahaffey, et al., 2019; Smith, Kaur, Orlowski, Singh, et al., 2019; I. Stephenson et al., 2011). Although TR-planted soybean can increase yields by as much as 23% (Bruns, 2011a, 2011b; Grichar, 2007), the evidence is not conclusive that TR planting in cotton results in consistent yield increases (Boykin & Reddy, 2010; Pettigrew, 2015; Reddy & Boykin, 2010; Reddy et al., 2009; D. Stephenson & Brecke, 2010; I. Stephenson et al., 2011).

Twin-row-planted cotton enhances canopy-intercepted photosynthetically active radiation (IPAR), which may drive higher yields (D. Stephenson & Brecke, 2010). This effect is also present in TR-planted soybean with the added benefits of the suppression of late-season weed germination and establishment due to faster canopy closure, increased plant survival rates, and improved nutrient and water use efficiencies (Bellaloui et al., 2015; Bowers et al., 2000; Bruns, 2011a, 2011b; Grichar, 2007; Smith, Kaur, Orlowski, Mahaffey, et al., 2019; Smith, Kaur, Orlowski, Singh, et al., 2019). The TR planting is robust to planter errors, which reduces the risk in the production process (Smith, Kaur, Orlowski, Mahaffey, et al., 2019). Smith, Kaur, Orlowski, Sing, et al. (2019) reported improved TR profitability of \$39–188 ha^{-1} for soybean.

1.2 | Skip-row irrigation

Skip-row irrigation is considered a best management practice (BMP) in the Mid-Southern United States (Leininger et al., 2019). It consists of applying water to every other furrow in the field. An early study shows that SRI on fields with residual deep tillage may reduce water application by up to 66% for corn and grain sorghum [*Sorghum bicolor* (L.) Moench] without a statistically significant effect on yields (Musick & Dusek, 1982). Soil texture is an important factor that determines how much water may be saved without affecting crop yields. Infiltration and lateral movement of water under SRI is greater in moderately and poorly drained soils (Leininger et al., 2019), while well-drained and coarse-textured soils risk exhibiting yield losses due to deep percolation and limited lateral flows (Ebrahimian, 2014). A study conducted on Bosket very fine sandy loam soils near the sites where the data for this article were taken shows that SRI can reduce water use without adverse effects on peanut (*Arachis hypogaea* L.) pod yields irrespective of different land preparation methods

(Leininger et al., 2019). The same study reported that SRI doubled profits in the dry year but did not affect profits in the wet year.

1.3 | The decision to irrigate and the value of simple decision rules

Economists model farmer behavior primarily as a production entity that behaves like a firm with a business objective. The business objective is typically a variation of maximizing profits or delivering a level of output at the minimum cost. Agricultural economists recognize that profit-seeking may not be the principal motivation for every farmer. For instance, many farmers in the Delta have wildlife considerations in managing their farmlands. Nonetheless, in the aggregate, farmers tend to make decisions about their production in a business-like fashion. Hence, the assumption of profit maximization is frequently used because it simplifies the analysis and predicts economic behavior reasonably well (Pindyck et al., 2009).

In this framework, the decision regarding how much of an input, such as irrigation water, to apply to the fields is determined "at the margin." This means that the decision to apply an input later in the growing season, such as irrigation water or pest and weed control, is made based on whether the treatment is expected to return a higher benefit than the cost of applying it: apply the input until the benefit of the last unit applied equals its cost (marginal cost = marginal revenue). The response of crop yields to the amount and timing of irrigation water applied depends on how much of other inputs have been used on the field (Saseendran et al., 2014). However, irrigation events can occur after most of the other inputs have already been applied, and it is acceptable to model crop yield response to water as a single-input function, as depicted in Figure 1.

A grower with perfect knowledge of a crop's response to irrigation water (Y_w) and precise control of the amount of irrigation water applied (w) would choose the amount of irrigation water that maximizes their profit (π_w). Observing current or expected crop prices (p) and water application costs (c_w), the profit function is expressed as $\pi_w = pY_w - c_w$. The marginal decision rule indicates that water is applied (w is increased) until the revenue due to yield gains equals the cost of the last mm of water applied—mathematically, until $p_w Y_{w^*}{}' = p\frac{\partial}{\partial w} Y_{w^*} = \frac{\partial}{\partial w} C_{w^*} = c'_{w^*}$.

As illustrated in Figure 1, the farmer with perfect knowledge of these components would achieve higher profits while conserving water than another grower who aims at achieving maximum yield. The lower the cost of applying the last mm of water and the higher the crop prices, the closer the profit-maximizing level of irrigation is to the yield-maximizing level of irrigation.

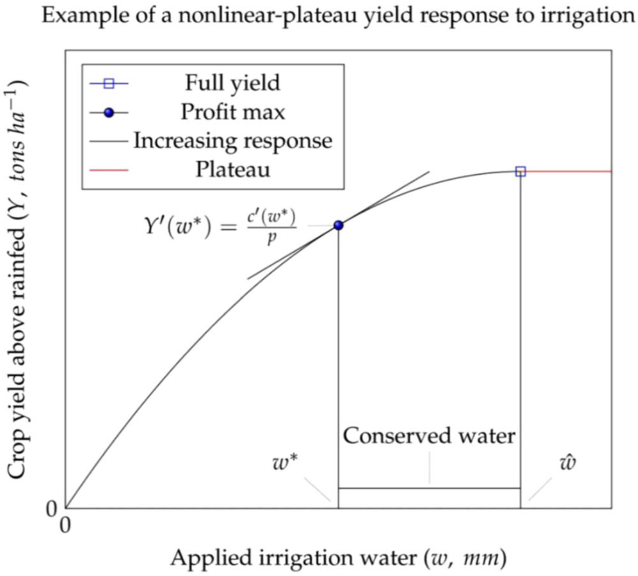

FIGURE 1 Illustration of the relationship between crop yield, applied irrigation water, and profits

Although this formula is useful as an analytic tool in the right setting, it is an inadequate decision-making tool. Farmers, like any other business manager, make their decisions with less-than-ideal information following simplified decision rules (i.e., rules of thumb) that are often informed as much by experience or perception as they are on available data analysis. Most growers have a good sense of what crop-yields their fields can achieve under rainfed (RF) and fully watered conditions, as well as how variable those yields can be, given weather conditions.

In the sequence of decisions, after they choose which crop to plant, they prepare the fields and apply the number of inputs that would allow them to achieve the best yield outcome given their seasonal weather expectations. With respect to the irrigation decisions, they have slightly better information because they have observed the weather outcomes and planting conditions to that point. However, under furrow irrigation, they do not have a millimetric control of the volume of water they apply—in fact, many irrigation wells in Mississippi do not have a flowmeter (Quintana-Ashwell et al., 2020). They decide when to start an irrigation event based on the observed and expected weather, perceived soil moisture, and plant growth stage, with the goal of achieving fully watered yield in mind. In terms of Figure 1, the farmer with perfect information is aiming at achieving maximum yield at $\hat{w}$; however, information is imperfect and irrigation water application is imprecise.

The actual total amount of water applied depends on what rules of thumb the grower follows to initiate and terminate irrigation events. Because the basic aim is to achieve the maximum yield the farmer has been gearing towards all season long, it is most likely that the actual application is in excess of the minimum volume required to achieve maximum yield (i.e., a volume larger than $\hat{w}$, situating the grower on the plateau section of the response curve). Farmers have a sense of the crop water requirements at different stages of the growing season, and they aim at delivering at least as much water as needed to fulfill that crop water requirement.

Simplified rules of thumb that allow irrigators to decrease their water application volumes and traverse the plateau in Figure 1 leftwards can result in significant water conserved in the aggregate without reducing the agronomic or financial performance of their farming operation. We analyze the profitability and water conservation potential of adopting SRI. Because the baseline is a BMP, the potential water and cost savings observed in actual farms are expected to be at least as promising as observed in the experiments reported in this article.

The baseline BMP is characterized by (a) irrigation events initiated when soil-matric potential reaches approximately −90 kPa (at 60-cm soil depths for soybean and 45-cm soil depths for cotton); (b) every furrow is watered; and (c) irrigation events are terminated once water reaches the end of the furrow (i.e., no irrigation runoff). To analyze the merits of SRI in terms of profitability and water conservation potential, we employ data published in Pinnamaneni, Annapalli, Reddy, and Fisher (2020) and Pinnamaneni, Anapalli, Reddy, Fisher, and Quintana-Ashwell (2020).

2 | MATERIALS AND METHODS

This article analyzes the farm profitability implications of the agricultural practices studied in two agronomic experiments reported in Pinnamaneni, Anapalli, Reddy, Fisher, and Quintana-Ashwell (2020) for soybean and in Pinnamaneni, Annapalli, Reddy, and Fisher (2020) for cotton. The field studies were conducted at the USDA-ARS, Crop Production Systems Research Unit farm located in Stoneville, MS, on Dundee silt loam soils (fine silty, mixed, active, thermic Typic Endoaqualfs) in 2018 and 2019. The fields were prepared with multiple tillage operations including disking, hipping, and rolling for bed formation. In the spring, the raised-ridge seedbeds were rehipped and their tops were smoothed before planting (Pinnamaneni, Annapalli, Reddy, & Fisher, 2020; Pinnamaneni, Annapalli, Reddy, Fisher, & Quintana-Ashwell, 2020). The seeding rates were set to achieve similar plant population densities for SR and TR planting geometries—approximately 336,000 plants ha^{-1} for soybean and 120,000 plants ha^{-1} for cotton. Irrigation was delivered via lay-flat polyethylene tubing (Polypipe, Delta Plastics) with total irrigation application measured with a McCrometer flowmeter. Soil-matric water potential was measured using Watermark sensors (Watermark 200SS, Irrometer Co.) installed at depths of 15, 30, and 60 cm.

2.1 | Data

Total volumes of irrigation water applied in 2018 were 220 and 115 mm for ARI and SRI soybean, respectively. About 195.4 and 96.2 mm of irrigation water was applied for ARI and SRI cotton, respectively. In 2019, 152 mm for ARI and 75 mm for SRI were applied to both crops. Precipitation data from the Mid-South Agricultural Weather Service, Delta Research and Extension Center, Stoneville, MS, weather station (adjacent to the experimental field) indicated 731 mm of precipitation were received in the 2018 crop season and 896 mm in the 2019 crop season. Due to extraordinarily dry planting conditions in 2018, all fields (including RF) received 92 mm of pumped groundwater after planting to aid germination. These germination-aiding volumes are not included in the irrigation water applied data in Table 1. Figure 2 illustrates the timing of precipitation, planting, and irrigation events by crop and year. A summary of mean yields, applied irrigation, water use efficiency, and profitability of treatments reported by the source studies (Pinnamaneni, Anapalli, Reddy, & Fisher, 2020; Pinnamaneni, Anapalli, Reddy, Fisher, & Quintana-Ashwell, 2020) is presented in Table 1.

The estimated irrigation water use efficiency (IWUE) has to be interpreted carefully. The articles that report the data we use here calculate IWUE for crop c planted with plant geometry g under irrigation scheme i as $IWUE_{icg} = \frac{Y_{icg}-Y_{rcg}}{I_{ic}}$, where Y_{icg} is the yield obtained under irrigation scheme i for crop c planted with row geometry g; Y_{rcg} is the yield for the same RF crop-geometry; and I_{ic} is the amount of irrigation water applied to that crop under that irrigation scheme. Consequently, comparisons across planting geometries are incorrect. For example, cotton under ARI in 2018 had a higher lint yield (1.74 Mg ha^{-1} vs. 1.69 Mg ha^{-1}) under TR geometry than under SR planting using the same amount of irrigation water (i.e., TR uses water more efficiently than SR), but the calculated IWUE is higher for SR ARI cotton because their reference yields (Y_{rcg}) are different.

2.2 | Economic analysis

We applied partial budget analyses to assess the profitability implications of the TR planting geometry and SRI management. The estimates were normalized by the corresponding RF crop-plant geometry combination by calculating the yield and profit changes from each treatment to the corresponding RF crop and planting geometry. To assess the relationship between risk and returns, we employed the variability reported for the yields to calculate the variability in returns.

Each treatment had different levels of costs and revenues. The revenue was calculated by multiplying the yields under each treatment for each crop by the average bid price. Soybean prices were obtained from reports by the USDA Economics,

TABLE 1 Mean yields, applied irrigation, water use efficiency, and profitability of treatments reported in the agronomic studies (Pinnamaneni, Annapalli, Reddy, and Fisher, 2020; Pinnamaneni, Anapalli, Reddy, Fisher, and Quintana-Ashwell, 2020)

Crop	Irrigation	Plant rows	Year	Yield	Production Cost	Returns over specified costs	Irrigation water applied	Irrigation Water Use Efficiency[a]	Profit change due to irrigation
				Mg ha^{-1}	——$ ha^{-1}——		mm	kg ha^{-1} mm^{-1}	$ ha^{-1}
Cotton	ARI	SR	2018	1.69 bc	2,508	153	195	0.61	76
			2019	1.87 b	2,446	152	152	2.17	129
		TR	2018	1.74 bc	2,518	231	195	−0.41	−230
			2019	2.31 a	2,453	761	152	3.68	454
	SRI	SR	2018	1.74 bc	2,492	246	96	1.77	170
			2019	1.87 b	2,427	169	75	4.40	146
		TR	2018	1.98 a	2,502	620	96	1.66	160
			2019	2.18 a	2,434	598	75	5.73	291
	RF[b]	SR	2018	1.57 c	2,404	77	–	–	–
			2019	1.54 c	2,120	23	–	–	–
		TR	2018	1.82 ab	2,413	460	–	–	–
			2019	1.75 bc	2,127	307	–	–	–
Soybean	ARI	SR	2018	4.3 e	1,297	(41.22)	220	3.18	291
			2019	4.1 e	1,398	(27.10)	152	1.97	−73
		TR	2018	5.0 d	1,306	154	220	3.64	434
			2019	4.6 d	1,405	133	152	3.95	−104
	SRI	SR	2018	4.2 e	1,277	(50.20)	115	5.22	282
			2019	4 e	1,378	(40.83)	75	2.67	−87
		TR	2018	4.9 d	1,286	145	115	6.09	426
			2019	4.5 de	1,385	119	75	6.67	−118
	RF	SR	2018	3.6 f	1,442	(332)	–	–	–
			2019	3.8 f	1,158	45.87	–	–	–
		TR	2018	4.2 e	1,449	(281)	–	–	–
			2019	4 e	1,167	237	–	–	–

Note. ARI, all-row irrigation; RF, rainfed; SR, single-row; SRI, skip-row irrigation; TR, twin-row. Cotton and soybean are separately tested for least significant difference in means. Same letter or letters indicate not statistically different ($P \leq .05$) in the source articles.

[a]Irrigation water use efficiency is calculated as $\text{IWUE} = \frac{\text{Yield}_{\text{irrigated}} - \text{Yield}_{\text{rainfed}}}{\text{Water applied}}$.

[b]In 2018, all plots received 92 mm of water shortly after planting to help germination due to dry conditions at the time.

Statistics and Market Information System. The average bid prices were calculated from reports obtained between 17 September and 1 November at county elevators in Greenville, MS, at $292.08 Mg^{-1} in 2018 and $334.33 Mg^{-1} in 2019. Cotton prices were obtained from the USDA Agricultural Marketing Service Cotton Price Statistics 2018–2019 report for base quality upland cotton in the Delta. Season average cotton market prices were reported at $1,580 Mg^{-1} in 2018 and $1,390 Mg^{-1} in 2019 (October report).

The production costs for RF SR-planted soybean and cotton were obtained directly from the Delta crop planning budgets from the Mississippi State University's Department of Agricultural Economics (MSU, 2018, 2019). The SRI crop costs were adjusted from the published planning budgets to reflect actual amounts of water applied to the fields (e.g., fuel, repair, and maintenance capital costs of pump and irrigation equipment). The additional production cost of TR planting was calculated from the difference between an SR planter and a TR planter in terms of the estimated purchase price, annual use, useful life, performance rate, and the direct and fixed cost per acre. The production cost under SRI for each crop and planting geometry was calculated adjusting for the actual volume of water applied. The effect of each irrigation treatment is presented for each crop and plant geometry in Table 1.

3 | RESULTS

Because crop prices and weather are highly variable, we analyzed the profitability of irrigated crops under both irrigation schemes, comparing them with the RF performance for each

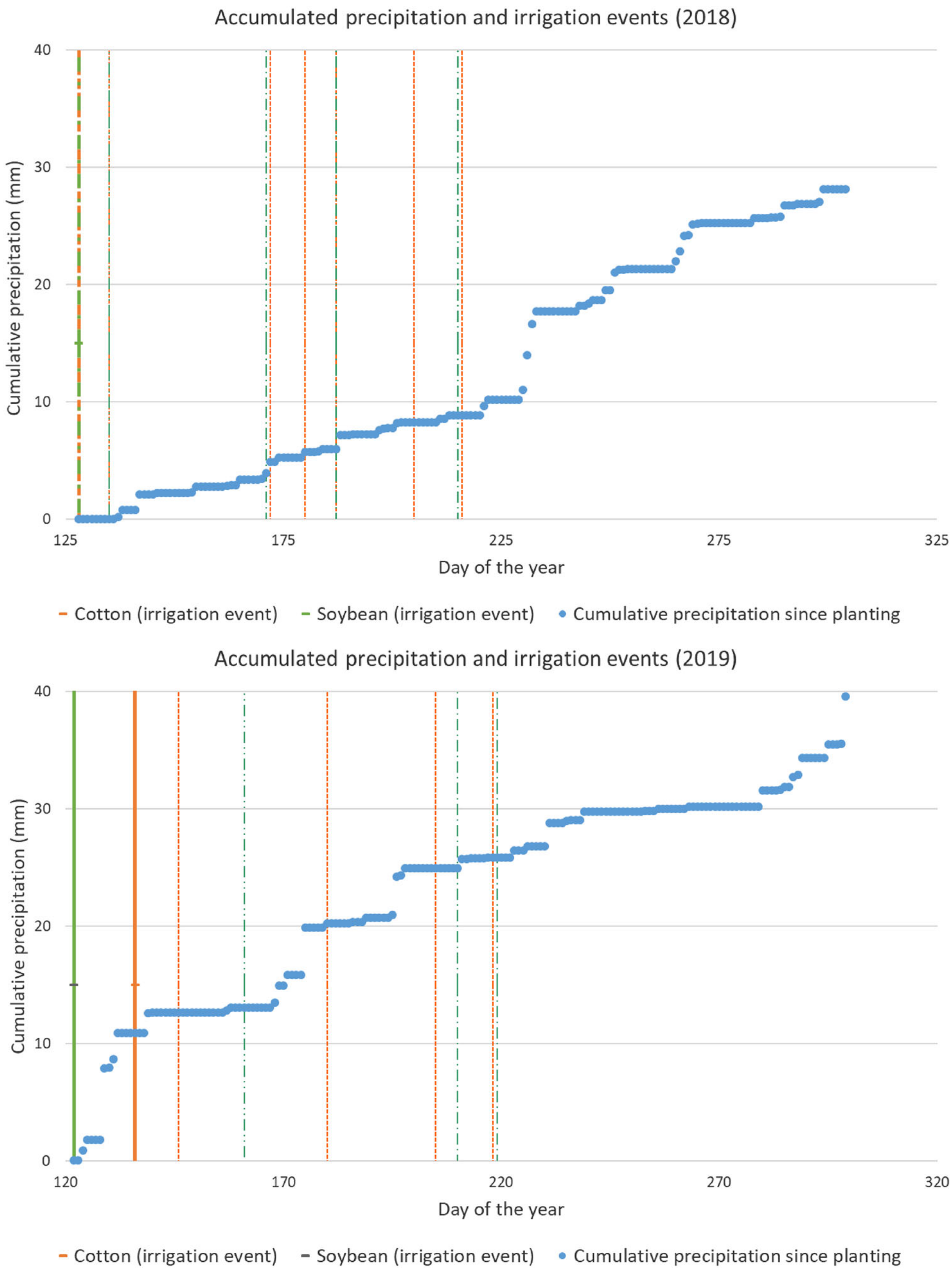

FIGURE 2 Recorded precipitation and timing of irrigation events

crop and planting geometry. Figure 3 is a graphical representation of the calculated profit changes (with confidence intervals) in Table 1 that shows the calculated irrigation rents from the field studies on cotton and soybean (Pinnamaneni, Anapalli, Reddy, & Fisher, 2020; Pinnamaneni, Anapalli, Reddy, Fisher, & Quintana-Ashwell, 2020). A positive rent from irrigation means that the planting geometry under a given irrigation treatment produced higher profits than the respective RF planting geometry—meaning that it resulted in higher estimated profits or lower estimated losses. In 2018, ARI cotton employing TR geometry resulted in \$230 ha^{-1} lower returns than TR planting in RF cotton. However, the largest improvement in profits was observed for ARI TR cotton in 2019 (\$454 ha^{-1}), which suggests there was an unknown factor affecting yields from this irrigation-planting geometry combination in 2018. In all other cases, irrigated cotton resulted in higher estimated profit than their RF counterpart. All-row irrigation SR cotton resulted in \$76 and \$129 ha^{-1} higher profits than RF in 2018 and 2019, respectively. Skip-row irrigation SR cotton improved returns over RF by \$170 and \$146 ha^{-1} in 2018 and 2019, respectively, while under TR, SRI increased profits over RF by \$160 and \$291 ha^{-1} in 2018 and 2019, respectively. Differences in precipitation received and its distribution within the growing season in each year and plant

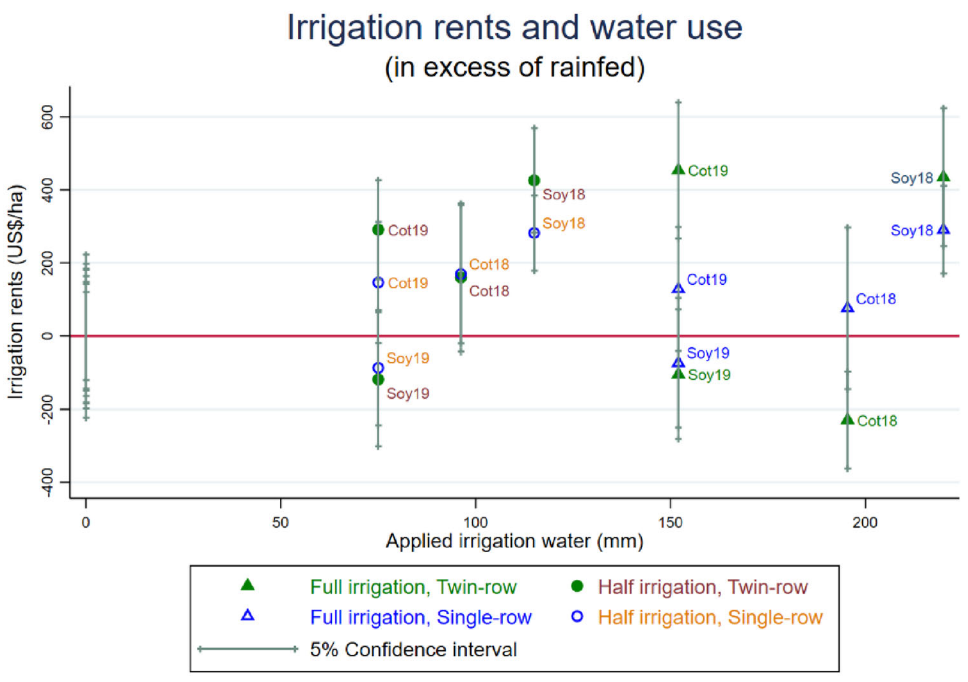

FIGURE 3 Profits above rainfed treatment by crop and planting geometry

root growth and distribution might have been responsible for differences among years and planting geometry for yield and profits. Precipitation received during the reproductive growth stages (July–September) was greater in 2018 than 2019 (Figure 2). Pinnamaneni, Anapalli, Reddy, and Fisher (2020) concluded that the cotton in ARI treatments in 2018 might have been subjected to soil waterlogging due to excess water resulting from heavy precipitation events after irrigation application in July and August months, which coincided with the boll formation and developmental growth stages in cotton. Soil waterlogging negatively effects cotton growth and results in lower yield and consequently, low net returns in 2018.

Irrigated soybean resulted in substantial gains over RF in 2018 with the largest gains for ARI TR planted soybean at \$434 ha^{-1}. Similarly, SRI TR soybean resulted in gains of \$426 ha^{-1}, ARI SR soybean in gains of \$291 ha^{-1}, and SRI SR soybean returned \$282 ha^{-1}. However, irrigated soybean did not financially outperform RF soybean in 2019. All-row irrigation SR and TR soybean returned \$73 and \$104 ha^{-1} less than their RF control, respectively, and SRI SR and TR soybean returned \$87 and \$118 ha^{-1} less than their RF control, respectively.

3.1 | Conversion from SR to TR planting geometry

Our partial budget analyses indicated that growers who convert from SR to TR planting can expect substantial payoffs regardless of the irrigation scheme. The physiological and agronomic advantages of TR over SR soybean production have been extensively reported (Smith, Kaur, Orlowski, Singh, et al., 2019). This study provides further evidence of the profitability of the practice. The existing evidence in the literature for TR cotton planting is inconsistent, but this article shows that cotton growers can expect a significant boost to their operational profits from TR planting in the conditions described here.

Due in part to depressed soybean prices associated with punitive tariffs imposed on U.S. soybean by the People's Republic of China, the expected gains in returns per hectare are larger for cotton than for soybean production. For cotton, TR planting geometry improved returns by \$334 ha^{-1} for RF, \$344 ha^{-1} for ARI cotton, and \$401 ha^{-1} for SRI cotton. Twin-row-planted soybean resulted in the highest estimated profit gains under irrigation (ARI or SRI) at \$178 ha^{-1} on average, while RF resulted in average gains of \$121 ha^{-1} in profits. On average, a grower with a cotton–soybean rotation may expect returns to increase by \$228 ha^{-1} for RF fields, \$261 ha^{-1} for ARI fields, and \$290 ha^{-1} for SRI fields. Table 2 summarizes the expected monetary benefits observed comparing SR to TR planting geometry in the experiments.

3.2 | Conversion from ARI to SRI

The field experiments indicated that substantial water savings may be achieved by irrigating every other furrow (SRI) instead of each (ARI) furrow (Pinnamaneni, Anapalli, Reddy, & Fisher, 2020; Pinnamaneni, Anapalli, Reddy,

TABLE 2 Benefits of conversion from single- to twin-row planting

Irrigation	Cotton			Soybean		
	2018	2019	Mean	2018	2019	Mean
	$ ha^{-1}					
All-row irrigation	77.55	609.54	343.55	195.29	160.04	177.66
Skip-row irrigation	373.98	428.99	401.48	195.29	160.04	177.66
Rainfed	383.44	284.54	333.99	51.29	191.43	121.36

Fisher, & Quintana-Ashwell, 2020). Skip-row irrigation in cotton reduced groundwater use by 99 mm in 2018 and 77 mm in 2019 for an average savings of 88 mm over the two years of the experiment. Similarly, the water savings for soybean were 105 mm in 2018 and 77 mm in 2019 for an average of 91 mm over the two years. The economic analysis indicated that conversion from ARI to SRI is profitable for cotton growers. This means that given their preferred planting geometry and plant population, they would obtain higher profits under SRI, on average. However, soybean growers are not expected to increase their profits migrating from ARI to SRI. Despite the cost savings involved in reduced levels of groundwater pumping, the crop's response to additional water is such that it still pays off to fully irrigate (at least in the context of these experiments). The implicit average cost of saving the water from SRI soybean is \$0.132 mm^{-1} (approximately \$1.36 per conserved acre-inch of groundwater). Table 3 summarizes the costs and benefits of SRI as a water-conserving practice.

3.3 | Risk and efficiency

In simple terms, the risk is the likelihood and magnitude by which the observed returns will deviate from its expected value. The partial budget analyses indicated the expected returns of different crop-geometry–irrigation combinations but omitted risk considerations. Figure 4 shows the expected returns for each crop-geometry–irrigation bundle and the risk associated with those returns expressed as their variability (standard deviation of returns). Taking any point as a reference, another point above it indicates a combination for which a higher return is expected. Similarly, another point to the left of that reference indicates a lower risk associated with that combination. The slope of the green and blue lines represents the return to risk associated with a fully irrigated crop under TR and SR planting geometry, respectively. From Figure 4, it is clear that TR planting geometry offers a much better risk–return proposition regardless of irrigation scheme or crop involved. For cotton, SRI also offers superior risk–return performance when compared with ARI. However, for soybean, the advantage is only marginal under TR planting and unfavorable under SR planting.

Figure 5 shows the level of expected (calculated average) returns per hectare under different crop-geometry–irrigation scheme bundles. This graph represents a concept of water productivity similar to IWUE. While IWUE may be understood as "more crop per drop," this representation (slope of ray from origin) illustrates the idea of "more buck per drop," whereby "buck" is a popular designation for US\$. The type of irrigation employed is represented by the level of water applied (x axis). In terms of the economic efficiency of irrigation water use, the graph shows that SRI and TR planted crops provide the highest returns for the amount of irrigation water applied. The graph also illustrates that SRI would result in cotton growers being able to profitably conserve water. However, soybean producers would see their bottom lines adversely affected by SRI.

For farmers in the Delta Region of Mississippi, there seems to be little downside risk to migrating to a TR planting geometry. On average, RF TR cotton and soybean outperformed ARI SR crops in terms of risks and returns. However, there is greater variability of returns for RF TR soybean than for ARI soybean. This suggests that a preference for irrigated soybean may be driven by risk aversion. There is no apparent increased risk in TR RF cotton when compared with ARI SR cotton.

TABLE 3 Effects of conversion from all-row irrigation (ARI) to skip-row irrigation (SRI) in cotton and soybean

Plant rows	Water savings			Profit differential			Conversion benefit		
	2018	2019	Mean	2018	2019	Mean	2018	2019	Mean
	mm ha^{-1}			$ ha^{-1}			$ mm^{-1}		
Cotton									
Single-row	99	77	88	93.20	17.77	55.49	0.940	0.231	0.585
Twin-row	99	77	88	389.63	-162.8	113.42	3.928	−2.114	0.907
Soybean									
Single-row	105	77	91	−8.98	−13.80	−11.39	−0.086	−0.179	−0.132
Twin-row	105	77	91	−8.99	−13.74	−11.37	−0.086	−0.178	−0.132

Note. A negative benefit of switching from ARI to SRI can be interpreted as the compensation a farmer may need to receive for implementing the water-conserving practice.

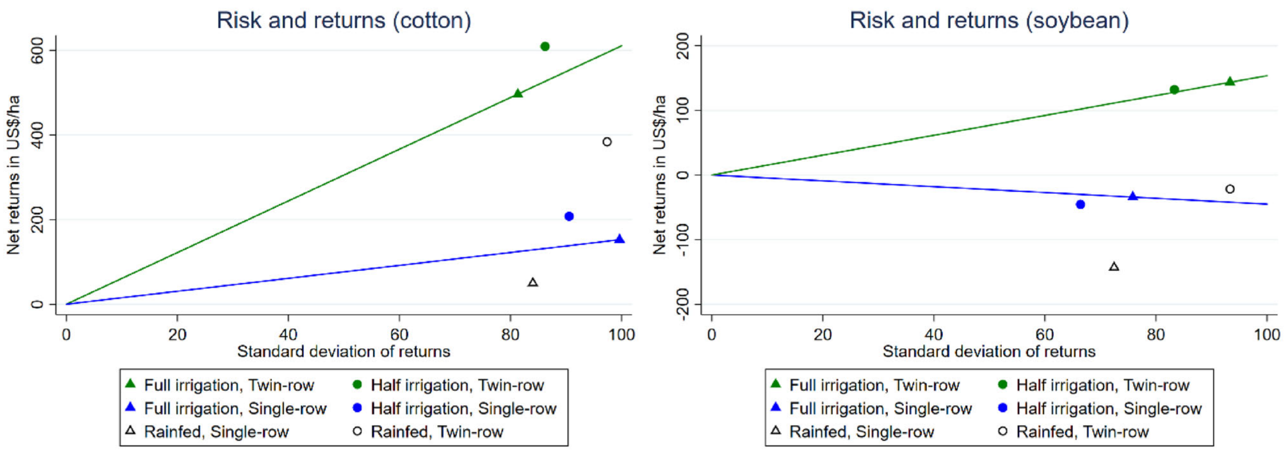

FIGURE 4 Comparison of returns to risk as represented by variability of returns

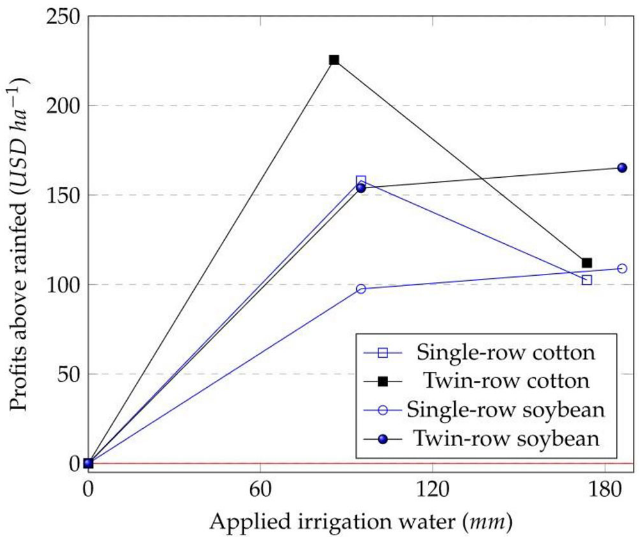

FIGURE 5 Economic productivity of irrigation water by planting geometry

4 | DISCUSSION

The results indicated that TR geometry offers better risk–return performance and improved economic efficiency of irrigation water use regardless of crop and irrigation scheme. The literature also offers consistent evidence that TR planting increases soybean yield but is not as clear for cotton. This article presents evidence that TR planting increases return regardless of irrigation. Furthermore, we offer additional evidence based on risk–return and economic efficiency that the practice is advisable. For irrigated crops, TR planting offers higher economic water use efficiency than SR planting geometry. Skip-row irrigation is a water-conserving and IWUE-improving irrigation practice. The data showed that cotton growers can nearly halve the amount of water applied in irrigation following current best management practices for furrow irrigation without adversely affecting yield while improving profits. Skip-row irrigation also exhibited better risk–return performance than ARI for the cotton experiments. However, they also showed that despite significantly improving the economic productivity of irrigation water, SRI comes at a cost to soybean growers.

The cost in lost profits to the soybean growers emerging from SRI is \$0.132 mm^{-1}. The USDA-NRCS invested over \$17 million over 4 yr on the adoption of various soil- and water-conserving practices. Based on Mississippi State University reports on the water-conserving potential of those practices, they estimate up to 178,854 M L year^{-1} in water savings, which implies a cost of \$0.97 mm^{-1} of conserved water. Consequently, directing incentive funds towards the adoption of SRI in soybean production may be an effective way to overcome the profitability issue for adoption by soybean growers.

The main caveat of this study is that the irrigation events were scheduled based on the BMP established for ARI crops. Skip-row irrigation events were delivered on the same dates as the ARI events. The initiations were determined based on readings of soil-matric potential in ARI plots, and no readings were reported for SRI plots. It is not clear if the benefits of SRI derive from allowing drier soil conditions or by another unmeasured effect resulting from alternating irrigated and nonirrigated rows. Before authoritative recommendations can be made regarding the adoption of SRI, additional agronomic research is needed to establish what drives the water savings and productivity gains.

The fact that the experiments were conducted following best management practices for furrow irrigation suggests that there is great potential to reduce overall water use in the Delta region of Mississippi at relatively low cost to producers; possibly even profitably.

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AUTHOR CONTRIBUTIONS

Nicolas Quintana-Ashwell: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Validation; Writing-original draft; Writing-review & editing. Saseendran S. Anapalli: Funding acquisition; Investigation; Project administration; Writing-review & editing. Srinivasa R. Pinnamaneni: Data curation; Investigation; Project administration; Writing-review & editing. Gurpreet Kaur: Writing-review & editing. Krishna N. Reddy: Writing-review & editing. Daniel Fisher: Writing-review & editing.

CONFLICT OF INTEREST STATEMENT

Authors declare no conflicts of interest.

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