MISSISSIPPI SOYBEAN PROMOTION BOARD

Cover Crop and Tillage Effects on Irrigation Application Efficiency, Runoff Volume, Transport, Soybean Grain Yield and Net Returns
52-2019 Final Report

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Abstract: Mid-southern USA soybean [*Glycine max* (L.) Merr.] producers are being pushed to increase adoption of conservation tillage systems as a means of increasing the application efficiency of gravity flow irrigation systems. This research was conducted to determine whether the efficiency of furrow-irrigation systems could be manipulated through conservation tillage systems while maintaining soybean productivity and profitability. Three experiments were conducted near Stoneville, MS on a Dubbs silt loam (Fine-silty, mixed, active, thermic Typic Hapludalfs) to determine the effects of reducing tillage and increasing ground cover residues on irrigation application efficiency, irrigation water use efficiency, soybean grain yield, and net returns above specified costs. In experiment 1, transitioning from conventional tillage to a conservation tillage system had no adverse effect on irrigation application efficiency, irrigation water use efficiency, soybean grain yield, or net returns above specified costs when subsoiling was included. For experiment 2, replacing subsoiling with a cereal rye or tillage radish cover crop in a conservation tillage system either had no effect or reduced irrigation application efficiency, irrigation water use efficiency, soybean grain yield, and net returns above specified costs up to 41%. In experiment 3, independent of cover crop, reducing tillage to only furrow creation had no adverse effect on irrigation application efficiency, irrigation water use efficiency, soybean grain yield, and net returns above specified costs relative to a conservation tillage system with subsoiling. Conservation tillage systems that include subsoiling maximize irrigation application efficiency and irrigation water use efficiency while minimizing adverse effects on

yield and net returns relative to conservation tillage systems that further reduce tillage and/or increase ground coverage with cover crops. Our data indicate that soybean producers in the mid-southern USA maximize furrow-irrigation functionality, yield, and profitability while minimizing risk by transitioning from a conventional tillage system to a conservation tillage system with subsoiling.

Introduction:

Implementation of soil health production systems can benefit the entire agricultural system when conducted properly. Historically, erosion mitigation was the primary reason for adopting soil health BMPs (Lahmar, 2010), with recent focus placed on conserving soil moisture (Price et al., 2009). Soil health programs employ three principles conjunctively to improve soil physiochemical properties, reduce erosion, and offsite agrochemical transport, that is, decrease soil disturbance, increase soil coverage, and crop rotation (Lahmar, 2010). In some U.S. regions these principles are established independently of each other and not combined into one soil health system.

The Mid-South, US is one region where soil health programs have not seen wide acceptance or implementation, yet could have a significant impact on production practices. Mid-South, US producers are skeptical of soil health programs due to associated production limitations, both perceived and actual. Irrigated agriculture in the Mid-South, US stands to reap the greatest benefits from soil health initiatives. Currently furrow irrigation is the prominent irrigation practice in the Mid-South, US. However, it is also one of the most inefficient uses of irrigation water. While many of these inefficiencies are inherent in the system itself, they are compounded by underlying soil issues.

Silt loam soils are some of the most productive soils in the region. These soils are plagued, however, by surface crusting which severely limits infiltration (Lado et al., 2004), while increasing runoff volumes (Endale et al., 2008) and erosion (Lahmar, 2010). Increases in runoff and soil loss also present the possibility of increased agrochemical transport. Past research, conducted at the Mississippi State Delta Research and Extension Center Stoneville, MS, indicates that irrigation application efficiencies may be increased through the use of surge valves or chemical soil amendments. Both of these approaches may add significant cost to producers.

Properly implemented soil health practices may increase furrow irrigation efficiency while simultaneously increasing producer returns through reduced inputs. Conservation tillage is a major component of soil health and has shown many benefits in regards to surface crusting, infiltration (Fageria et al., 2005), and agrochemical transport (Reddy et al., 2003). By definition, conservation tillage is any tillage operation that maintains 30% coverage of the soil surface by plant residue at planting (Lampurlanes and Cantero-Martinez, 2006). This definition leaves considerable variation in actual tillage operations performed, ranging from strict no-tillage (NT) to fall seed-bed preparation. Fall seed-bed preparation is the predominant tillage system in the Mid-South, US. While this system may accumulate significant plant residue amounts during the winter, the soil surface remains exposed for extended periods of time, potentially increasing soil crusting potential.

Fall cover crops are a soil health BMP that protect the soil surface during fallow periods (Dabney et al., 2001). Cover crops preserve soil structure from destructive forces that induce crusting, such as raindrop impact (Acuna and Villamil, 2014) and flowing water (Gabriels et al., 1997). Cover crops also increase surface porosity through root decomposition (Balkcom et al., 2007). Actively growing cover crops scavenge residual nutrients from the surrounding soil

(Dabney et al., 2001), minimizing nutrient leaching and aiding in nutrient management (Olson et al., 2010). Potential negative impacts of cover crops include yield reductions (Clark et al., 2007; Dabney et al., 2001), delayed cash crop emergence (Acuna and Villamil, 2014), and soil water depletion (Blanco-Canqui et al., 2013).

Many investigators suggest a 3-5 year time period before soil health benefits are fully realized when switching to conservation practices (DeLaune et al., 2012; Raper et al., 2000; Reddy et al., 2009). Benefits associated with adopting soil health BMPs including improved soil physiochemical properties, reduced erosion, and decreased off-site agrochemical transport vary based upon geographic location and regional agricultural production practices (DeLaune et al., 2012). Therefore, the objective of this study was to determine the effect of conservation tillage (conventional, reduced, zone) with cover crops [cereal rye (*Secale cereale* L.), tillage radish (*Raphanus sativus* L.)], no cover crop] on soybean grain yield, net returns above specified costs, and irrigation application efficiency.

Materials and Methods:

This project was conducted at Mississippi State University's, Delta Research and Extension Center in Stoneville, MS from 2015-2019. Soils of the field consisted of Dubbs silt loam and Bosket very fine sandy loam (Soil Survey Staff, 2015). Twenty-one plots were established in 2003 by the USDA-ARS in Stoneville, MS. Field grade falls from North to South and West to East following precision leveling. Cotton (*Gossypium hirsutum*) was grown from 2003 to 2010, and from 2011 to 2014 corn (*Zea mays*) was grown. Beginning in the spring of 2015 continuous soybean was grown.

Experimental units were 8-rows wide by approximately 170-m long with 102-cm wide rows and were hydrologically separated by 3.1-m wide levees. Culverts were fitted with

Teledyne Isco 2150 area velocity flow module sensors (Isco, Inc., Lincoln, Nebraska) and GLS Compact Composite Samplers (Isco, Inc., Lincoln, Nebraska) to measure runoff volume and capture water quality samples. A McCrometer flow tube with attached Mc®Propeller bolt-on saddle flowmeter (McCrometer Inc., Hemet, California) was installed on the riser to measure application volume.

Year one of the study was a transition year and consisted of four treatments with three replications arranged in randomized complete block design. Treatments included reduced tillage/winter fallow (RT/WF), reduced tillage/cereal rye cover (RT/RC), zone tillage/winter fallow (ZT/WF), and conventional tillage/winter fallow (CT/WF). Beginning in year two three additional treatments of reduced tillage/tillage radish cover (RT/TR), reduced tillage/sub-soiling (RT/SS), and zone tillage/tillage radish cover (ZT/TR) were added. Tillage operations were conducted as follows: Reduced tillage treatments were disked twice followed by bed formation in the fall after harvest. Zone tillage treatments were planted flat, and one pass was made with a sweep plow just prior to irrigation initiation for furrow creation. Conventional tillage treatments were disked twice in the fall after harvest and left flat through the winter, followed by one pass with a field cultivator and bed formation in the spring. One pass was made across RT and CT, with the exception of RT/RC, prior to irrigation initiation for furrow preparation. Rye and tillage radish were seeded using a Great Plains drill (Great Plains Manufacturing Inc. Salina, Kansas) at 67.2 kg ha^{-1} and 11.21 kg ha^{-1}, respectively.

All agronomic practices outside of tillage and irrigation scheduling were conducted according to Mississippi State University Extension service recommendations. Burn down of all plots was conducted on May 1st, April 26th, May 8th, and April 25th for 2015, 2016, 2017, and 2018, respectively. Tillage radish were chemically desiccated on February 10th, and March 21st, respectively, for 2016 and 2017, in 2018 winter kill was achieved and any regrowth continued until the April 25th burn down application. Rye cover crop was chemically desiccated with glyphosate at 1.26 kg ha^{-1} acid equivalent (ae) at the soft dough growth stage followed by rolling in the direction of planting using a four-row roller packer. Remaining treatments were desiccated using glyphosate and paraquat tank mixed at 1.26 and 1.55 kg ha^{-1} ae, respectively. Cover crop desiccation occurred two weeks prior to soybean planting on May 14th, May 11th, and May 9th, in 2015, 2016, 2017, and 2018 in accordance with recommendations described by Kornecki et al., (2012). Soybeans were planted directly into rye residue and any natural winter vegetation residue in other treatments. Soybean planting was achieved using a Monosem four row twin-row planter (Monosem® Inc./North America, Edwardsville, Kansas) at a rate of 345,935 seeds ha^{-1}.

Biomass samples were collected prior to cover crop termination. Biomass was determined by removing all cover crop residue from within 0.25-m^2 polyvinyl chloride squares (Kornecki et al., 2012) and drying for 72 hours at 60 C (Locke et al., 2005). Six samples were taken from the length of the plot to provide adequate representation along plot length. Percent ground cover was conducted on all plots just prior to soybean planting. Readings were calculated using the meterstick method (Hartwig and Laflen, 1978). Ten locations were randomly selected from the length of the plot.

The middle six rows of each plot were mechanically harvested and weighed using a portable weigh cart. Moisture content was determined and yields were adjusted to 130 g kg^{-1} moisture for analysis.

Irrigation was scheduled using FAO-56 and initiated at a 20.6 ha mm deficit, with 30.9 ha mm applied per irrigation event. Irrigation advance time was determined by:

$$A_T = T_2 - T_1$$

where A_T is the advance time; T_1 is irrigation start time; and T_2 is the time when the wetting front reached 170-m. Irrigation application efficiency was calculated by:

$$\mathrm{IAE} = \frac{V_A - V_R}{V_A} \times 100$$

where IAE is irrigation application efficiency; V_A is irrigation volume applied (82,910-L plot^{-1} irrigation^{-1}); and V_R is irrigation runoff volume.

Economic analysis was calculated for net returns above specified costs. Enterprise budgets were developed using Mississippi State University Delta Planning budgets for 2016, 2017, 2018, 2019, and 2020. Soybean prices were based on current cash value at Greenville, MS at the time of harvest. Results were analyzed using the GLIMMIX 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 $\alpha \leq 0.05$.

Results and Discussion:

Soybean Grain Yield

In experiment one, we hypothesized that the development of restrictive soil layers would reduce soybean grain yield in conservation tillage systems. Treatment interacted with year to have an effect on soybean grain yield (P = 0.0002; Table 1). As hypothesized, reducing surface tillage decreased soybean grain yield in RT/WF up to 8% compared to that of CT/WF in two of four years. However, fracturing the restrictive soil layer by with subsoiling maintained or improved soybean grain yield in RT/SS up to 18% of that reported for CT/WF in 3 out of 4 years.

In experiment two, we hypothesized that tillage could be further reduced by replacing subsoiling with a cereal rye or tillage radish cover crop. Pooled across years, treatment had an effect on soybean grain yield ($P = 0.0266$; Table 2). Relative to RT/SS, planting a fall cereal rye cover crop maintained soybean grain yield, while planting a fall tillage radish cover crop reduced soybean grain yield 12%. These data indicate that soybean grain yield can be maintained by replacing subsoiling with a cereal rye cover crop in conservation tillage systems.

In experiment three, it was hypothesized that soybean grain yield would be reduced by planting flat rather than on a raised seed-bed. Contrary to the hypothesis, planting flat, with or without a cover crop, had no effect on soybean grain yield ($P = 0.4986$; Table 3). Pooled across treatments and years, soybean grain yield was 56.5 bu/acre. Lack of soybean response to tillage system and cover crop is most likely due to a combination of soybean sensitivity to tillage and irrigation. It is most likely that soybean response to tillage was masked by irrigation. Our data indicate that Mississippi soybean producers can adopt conservation tillage systems so long as they include subsoiling, a cereal rye cover crop, or zone tillage and maintain soybean productivity on silt loam-textured soils.

Economic Analysis

In experiment one, it was theorized that lost income would not be recouped through savings associated with reduced tillage. Treatment and year interacted to have an effect on net returns above total specified costs ($P = 0.0002$; Table 1). Relative to CT/WF, RT/SS maintained or improved net returns above specified costs up to 68% in three of four years, while RT/WF maintained or decreased net returns above specified costs in all years. Our data indicate that if conservation tillage systems are implemented on medium- to coarse-textured soils in the mid-southern USA, then subsoiling should be included in the system to maximize net returns above specified costs.

In experiment two, it was assumed that costs savings associated with removing subsoiling operations would offset additional costs of planting cover crops. Pooled across years, treatment had an effect on net returns above specified costs (P = 0.0032; Table 2). In contrast, net returns were reduced in soybean production systems which included a cover crop. Including a tillage radish or cereal rye cover crop reduced net returns above specified costs by up to 41% relative to RT/SS. Without positive yield influences, costs associated with planting and desiccating cover crops cannot be recouped by simply removing one tillage operation.

In experiment three, it was theorized that on-farm profitability would be increased if tillage was reduced to an absolute minimum, compared to RT/SS. As treatment and the interaction of treatment and year had no effect on net returns above specified costs our theory was not true (P = 0.3724; Table 3). Net returns above specified costs were $215.67/acre, pooled across treatments and years. The lack of response is attributed to the relatively low costs of removed tillage operations, relative to remaining inputs, and an absence of yield response (Reddy, 2001, 2002). Averaged across years, costs associated with subsoiling, disking, and seed-bed formation were $32.47/acre while costs for inputs shared between all soybean production systems were $263.55/acre.

Irrigation Application Efficiency

It was theorized, in experiment one, that increasing ground cover by decreasing tillage would increase irrigation application efficiency. Contrary to our theory, conservation tillage systems either had no effect or decreased irrigation application efficiency up to 29% (Table 4). Lack of positive effects on irrigation application efficiency by conservation tillage systems is attributed to cultivation of furrows prior to the first irrigation. This tillage operation removed all plant residue from the furrow resulting in the decreased application efficiency in RT/WF, compared to CT/WF. Relative to CT/WF, including subsoiling in a reduced tillage system maintained irrigation application efficiency. The large, semi-stable channels produced by subsoiling allowed greater water infiltration, thereby increasing application efficiency.

In experiment two, we assumed that replacing subsoiling with a cover crop in conservation tillage systems would maintain or improve irrigation application efficiency. As assumed, replacing subsoiling with a cover crop had no effect on irrigation application efficiency ($P = 0.9384$; Table 2). These data indicate that replacing subsoiling with a cereal rye or tillage radish cover crop allows for further tillage reductions without negatively effecting irrigation application efficiency.

It was hypothesized, in experiment three, that reducing tillage to only furrow creation would maintain irrigation application efficiency relative to RT/SS. Furthermore, we theorized that positive effects of no-tillage on irrigation application efficiency would be increased when cover crops were included. In contrast, minimizing tillage to only furrow creation had no effect on irrigation application efficiency, regardless of cover crop ($P = 0.9895$; Table 3). These data indicate that furrow-irrigation functionality can be maintained similar to that of RT/SS while reducing tillage to an absolute minimum.

Conclusion

The objective of this study was to determine the effect of conservation tillage (conventional, reduced, zone) with cover crops [cereal rye, tillage radish, no cover crop] on soybean grain yield, net returns above specified costs, and irrigation application efficiency. Conservation tillage systems may be adopted by Mississippi soybean producers so long as subsoiling is included as RT/WF reduced soybean grain yield and net returns up to 8% in all years whereas RT/SS maintained or increased soybean grain yield and net returns up to 68%. While subsoiling may be replaced by a cereal rye cover crop without a negative effect on soybean productivity net returns were reduced up to 41%. Similarly, replacing subsoiling with a tillage radish cover crop always reduced soybean productivity and net returns. Adoption of zone tillage systems on silt loam-textured soils is a viable option for Mississippi soybean producers as there were no negative effects on soybean productivity, profitability, or irrigation application efficiency. However, producers should be aware that planting soybean flat, instead of on a raised seed-bed, increases the risk of having to replant following heavy spring rains.

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Table 1. Soybean grain yield (Yield) and net returns above specified costs (Returns) of an irrigated conservation tillage/cover crop soybean study conducted in Stoneville, MS on a Dubbs silt loam.

Year	Tillage*	Yield	Returns
		— kg ha^{-1} —	— $ ha^{-1} —
2015	CT/WF	67 a†	274.23 ab
	RT/WF	66 a	279.22 a
	RT/SS	64 a	247.35 b
2016	CT/WF	64 a	354.21 a
	RT/WF	55 b	284.03 b
	RT/SS	57 b	289.28 b
2017	CT/WF	52 a	212.50 ab
	RT/WF	48 b	189.97 b
	RT/SS	53 a	229.17 a
2018	CT/WF	57 b	109.82 b
	RT/WF	58 b	136.23 b
	RT/SS	66 a	184.24 a

* CT/WF = conventional tillage/winter fallow; RT/WF = reduced tillage/winter fallow; RT/SS = reduced tillage/subsoiling.

† Numbers within a year in a column followed by the same letter are not different at $P \leq 0.05$.

Table 2. Soybean grain yield (Yield), net returns above specified costs (Returns), and irrigation application efficiency (IAE) of an irrigated conservation tillage/cover crop soybean study conducted in Stoneville, MS on a Dubbs silt loam.

	Yield	**Returns**	**IAE**
Treatment*	kg ha^{-1}	— \$ ha^{-1} —	— % —
RT/SS	59 a	234.23 a	62 a
RT/RC	55 ab	168.32 b	65 a
RT/TR	52 b	137.92 b	63 a

* RT/SS = reduced tillage/subsoiling; RT/RC = reduced tillage/rye cover; RT/TR = reduced tillage/tillage radish.

† Numbers within a column followed by the same letter are not different at the $P \leq 0.05$ level of significance.

Table 3. Soybean grain yield (Yield), net returns above specified costs (Returns), and irrigation application efficiency (IAE) of an irrigated conservation tillage/cover crop soybean study conducted in Stoneville, MS on a Dubbs silt loam.

	Yield	**Returns**	**IAE**
Treatment*	kg ha^{-1}	— $ ha^{-1} —	— % —
RT/SS	59 a	234.23 a	62 a
ZT/WF	54 a	225.46 a	63 a
ZT/TR	56 a	183.68 a	62 a

* RT/SS = reduced tillage/subsoiling; ZT/WF = zone tillage/winter fallow; ZT/TR = zone tillage/tillage radish.

† Numbers within a column followed by the same letter are not different at the $P \leq 0.05$ level of significance.

Table 4. Irrigation application efficiency (IAE) for a furrow-irrigated conservation tillage soybean study conducted in Stoneville, MS on a Dubbs silt loam.

Treatment	IAE
	———— % ————
CT/WF	55 a
RT/WF	39 b
RT/SS	68 a

[*] CT/WF = conventional tillage/winter fallow; RT/WF = reduced tillage/winter fallow; RT/SS = reduced tillage/subsoiling.
[†] Numbers within a column followed by the same letter are not different at the $P \leq 0.05$ level of significance.