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Title: Agronomic and Irrigation Efficiency Impacts of Conservation Tillage and a Cereal Rye Cover Crop in Soybean Production

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ABSTRACT

Soil "health" best management practices (BMPs) have potential to improve agricultural production systems when applied properly, but few Mid-South producers have adopted production systems that promote soil health. This study was conducted to determine the effect of cover crop [no cover or cereal rye (*Secale cereale* L.] and tillage (conventional tillage, reduced tillage, no-tillage/furrow sweep) on soybean (*Glycine max* L.) yield components, economics, irrigation application efficiency, and agrochemical transport.

The experimental design was a randomized complete block with three replications of each treatment: conventional tillage (CT), minimum tillage (MT), minimum tillage/rye cover (MT/RC), and no-tillage/furrow sweep (NT/FS). Experimental units (8.13-m wide by x 170-m long) were planted with soybean at 345,935 seed ha^{-1} and were instrumented to mass balance the off-site transport of water, sediment, and agrochemicals.

Soybean yield components, irrigation water use efficiency, and economic returns were not different among tillage and cover crop systems. Minimum tillage/rye cover and NT/FS reduced furrow irrigation advance time by at least 65% relative to CT and MT. Irrigation application efficiency decreased in the order or NT/FS (87%) = MT/RC (82%) > CT (69%) > MT (44%). No-tillage and MT/RC reduced cumulative sediment loss by at least 66% relative to CT and MT. Relative to CT, only NT/FS reduced total Kjeldahl N. Total P decreased in the order of MT (0.07 kg ha^{-1}) > MT/RC (0.04 kg ha^{-1}) = CT (0.03 kg ha^{-1}) = NT/FS (0.02 kg ha^{-1}). Soil health BMPs including no-tillage and cereal rye cover crops have no adverse effect on soybean yield components or economic returns, but have potential to increase surface water quality and reduce groundwater withdrawals.

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; e.g., 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 producers are skeptical of soil health programs due to associated production limitations, both perceived and actual. Irrigated agriculture in the Mid-South stands to reap the greatest benefits from soil health initiatives.

Currently furrow irrigation is the predominant irrigation practice in the Mid-South. 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 seedbed preparation. Fall seedbed preparation is the predominant tillage system in the Mid-South. 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 cover crop (no cover or cereal rye) and tillage (conventional tillage, reduced tillage, no-tillage/furrow sweep) on soybean yield components, economics, irrigation application efficiency, and agrochemical transport.

MATERIALS AND METHODS

This project was conducted at Mississippi State University's Delta Research and Extension Center in Stoneville, MS in 2015. 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 70-m long with 102-cm-wide rows that 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 M^{c}Crometer flow tube with attached M^{c}Propeller bolt-on saddle flowmeter (McCrometer Inc., Hemet, California) was installed on the riser to measure application volume.

The study consisted of four treatments with three replications arranged in a randomized complete block design. Treatments included minimum tillage (MT), minimum tillage/cereal rye cover (MT/RC), no-tillage/furrow sweep (NT/FS), and conventional tillage (CT). Tillage operations were conducted as follows. Minimum tillage treatments were disked once followed by bed formation in the fall after harvest. No-tillage/furrow sweep 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 one pass in the fall after harvest and left flat through the winter, followed by one pass disking and bed formation in the spring. One pass was made across MT and CT prior to irrigation initiation for furrow preparation. Rye was seeded using a Great Plains drill (Great Plains Manufacturing Inc. Salina, Kansas) at 67.2 kg ha^{-1}.

All agronomic practices outside of tillage and irrigation scheduling were conducted according to University recommendations. Burndown of weeds in all plots was conducted on May 1st. Rye cover crop was chemically desiccated with glyphosate at 1.26 kg ha^{-1} acid equivalent (ae) 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 2 weeks prior to soybean planting on May 14th 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 and percentage ground cover measurements were conducted prior to rye termination. Biomass was determined by removing all rye 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 readings were calculated using the meterstick method (Hartwig and Laflen, 1978). Ten locations were randomly selected from the length of the plot.

Yield components were quantified by collecting 1-m harvest plant stands from two locations within each plot. Plants m^{-1} of row, plant height, nodes plant^{-1}, pods plant^{-1}, weight of pods and seed, weight of seed, and weight of 1,000 seed were determined for each sample. Middle six rows of each plot were mechanically harvested and weighed using a portable weigh cart. Yields were adjusted to 150 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:

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

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.

Water samples were analyzed for total solids, filtered solids, suspended solids, ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), total Kjeldahl nitrogen (TKN), total phosphorus (TP), ortho-phosphate, and total dissolved organic carbon (TDOC). Total and filtered solids were determined using American Public Health Association procedures (American Public Health Association, 1997a, 1997d), and suspended solids were determined by calculating the difference between total solids and filtered solids. Samples were vacuum filtered and filtrate was analyzed for NH_4^+, NO_2^-, NO_3^-, and soluble P (American Public Health Association, 1997b, 1997c, 2000a, 2000b; Locke et al., 2015). Ortho-phosphate was determined by digestion of unfiltered samples in H_2SO_4 with ammonium persulfate (American Public Health Association, 1997c). Analyses for filtered and digested samples were performed using a ThermoSpectronic Genesys™ 10 ultraviolet spectrophotometer (Spectronic Instruments) with a detection limit of 0.01 mg L^{-1} (Locke et al., 2015). Total phosphorus was determined by digesting unfiltered samples in H_2SO_4 with ammonium persulfate (American Public Health Association, 1997c). Total Kjeldahl nitrogen was determined with unfiltered runoff samples by digestion on a micro-Kjeldahl block digester followed by analysis with a Lachat QuickChem 8500 Series II autoanalyzer (Lachat Instruments) using Lachat Method 10-107-06-2-E (Locke et al., 2015). Samples were then filtered and analyzed using an Apollo 9000 combustion TOC analyzer (Teledyne Tekmar) to determine TDOC (Locke et al., 2015).

Economic analysis was calculated for net return above specified costs (Table 1). Economic returns were then adjusted to reflect potential savings attributed to cereal rye weed control, increased irrigation application efficiency, and both weed control and irrigation application efficiency. Adjustments for weed control were made by removing herbicide applications after rye desiccation for MT/RC treatments only, whereas adjustments for irrigation application efficiency were calculated by determining the amount of irrigation water required to recharge the soil profile from a 20.6 ha mm deficit based upon calculated efficiency percentages and adjusting volume of irrigation water applied.

RESULTS AND DISCUSSION

Soybean Yield and Yield Components.

Soybean yield and yield components were not different among treatments ($P \geq 0.1509$)(Table 2). Current literature presents varying soybean yield responses to tillage and cover crop. Watts and Torbert (2011) reported that tillage significantly impacted soybean grain yield in four of nine years; however, these four years were split evenly between conventional tillage and no-tillage, with each having significantly higher yields for two of the four years. In contrast, Delate et al. (2011) reported significantly lower yields for soybean grown under no-tillage. The soybean grain yield data for rye cover crop agrees with Reddy et al. (2003), Ruffo et al. (2004), and Smith et al. (2011), who found no significant soybean grain yield reductions due to cereal rye cover crop. Therefore, in the Mid-South US, implementation of no-tillage and cereal rye cover crops on silt loam textured soils should have no adverse effect on soybean grain yield or yield components.

Economics.

Net return above specified costs, net return adjusted for weed control, net return adjusted for irrigation application efficiency, and net return adjusted for weed control and irrigation application efficiency was not different among treatments ($P \geq 0.243$) (Table 3). These economic return data indicate that additional costs associated with cereal rye seed and desiccation can be recovered on silt loam textured soils even if tillage or cover crop does not increase irrigation application efficiency or weed control.

Irrigation Application Efficiency.

Evaluated production systems that promote soil health improved irrigation application efficiency, extended furrow advance times, and reduced runoff volume. Pooled over irrigation events, MT/RC and NT/FS increased furrow advance times by at least 65% relative to CT and MT (Table 4). Similarly, furrow advance times were reported to be at least 41 and 50% greater with a desiccated cover crop mulch and continuous cover crop, respectively (Gulick et al., 1994). Increasing furrow advance times allows irrigation water to remain in the furrow longer, potentially increasing infiltration and decreasing runoff volumes.

Cumulative irrigation runoff varied among treatments. No-tillage/furrow sweep reduced runoff volumes by at least 60% relative to MT and CT, however, cumulative runoff for MT/RC was only different from MT (Table 4). Others have reported that MT systems with a wheat or cereal rye cover crop reduced runoff by at least 10% relative to CT (Kaspar et al., 2001; Yoo et al., 1989). Production systems that reduce irrigation runoff have implications for irrigation application efficiency.

Irrigation application efficiency varied among tillage and cover crop systems. Irrigation application efficiency for MT/RC and NT/FS was at least 13% greater than CT and MT ($P = 0.0002$) (Table 4). Irrigation application efficiencies calculated for MT/RC and NT/FS exceed single application and cyclic application efficiencies of 38 and 55% respectively (Tyler et al., 1996) and approach the efficiency of high end drip irrigation systems which can reach 98% (Yohannes and Todesse, 1998). These data indicate that implementation of soil health production systems can increase furrow advance times, decrease irrigation runoff volumes, and improve irrigation application efficiency on a silt loam textured soil in the Mid-South US.

Sediment Transport.

Soil health BMPs reduced off-site sediment transport ($P \leq 0.0003$). Relative to CT and MT, MT/RC and NT/FS reduced cumulative sediment loss by 65% (Table 5). Decreased TS transport in MT/RC and NT/FS was attributed primarily to reductions in the loss of solids > 0.45 mm compared to CT and MT ($P = 0.0218$). Reductions in sediment transport of at least 52 and 88% have been reported for no-tillage and cover crops, respectively (Merten et al., 2015, Yoo et al., 1988). Therefore, it is possible to reduce the offsite transport of total solids on silt loam textured soils through implementation of best management practices that promote soil health.

Nitrogen Transport.

Offsite transport of TKN and analyzed N species was variable among soil health BMPs. Relative to CT, NT/FS decreased TKN by 57% but was not different among MT, MT/RC, and CT (Table 6). Ammonium losses were not different among treatments ($P = 0.0828$). The transport of NO_2^- and NO_3^- were not different between MT/RC, NT/FS, and CT, while losses from MT were 6.4-fold greater than that of CT ($P \leq 0.0086$). Others have reported reductions in TKN transport of at least 24% through no-tillage and 79% with a wheat cover crop (Franklin et al., 2012; Yoo et al., 1988). Franklin et al. (2012), reported TKN loss from CT was 3.4-fold greater than no-tillage. Transport of NH_4^+ varies, with reports of 31 and 71% reductions by no-tillage and cover crops (Yoo et al., 1988) and 49% increase in off-site transport with no-tillage (Franklin et al., 2012). Nitrate transport has been reduced by at least 54% in no-tillage and 83% by a wheat cover crop (Franklin et al., 20012; Yoo et al., 1988). Conversely, our data for soil health BMPs indicate that only NT/FS has potential to reduce total N transport on silt loam textured soils.

Phosphorus Transport.

Total P and ortho-phosphate transport differed among soil health BMPs (Table 7). Total P transport was reduced in the order of MT > MT/RC = CT = NT/FS ($P < 0.0001$). Ortho-phosphate transport was reduced in all treatments compared to MT. Minimum tillage/rye cover had significantly greater transport than NT/FS with both treatments similar to CT. Off-site transport of ortho-phosphate in no-tillage increased from 1.3% to 58% relative to CT (Bertol et al., 2007; Franklin et al., 2012). Conversely, total phosphorus losses were 2.7-fold greater in CT than no-tillage (Franklin et al., 2012). These data indicate that soil health BMPs will not reduce the off-site transport of TP and ortho-phosphate on silt loam textured soils.

CONCLUSIONS

The objective of this study was to determine the effect of cover crop (no cover or cereal rye) and tillage (conventional tillage, reduced tillage, no-tillage/furrow sweep) on soybean yield components, economics, irrigation intake rate, irrigation water use efficiency, and agrochemical transport.

Soil health BMPs including cereal rye cover crop and conservation tillage can be applied to silt loam textured soils across the Mid-South without adversely affecting soybean yield components, yield, or economic return above specified costs. Irrigation application efficiency can be improved on silt loam textured soils by implementing no-tillage or rye cover crops to efficiencies similar to that of overhead sprinkler systems. Moreover, adoption of no-tillage or rye cover on silt loam textured soils can reduce cumulative sediment loss by at least 66%. However, the adoption of soil health BMPs on silt loam textured soils will have minimal to no impact on off-site N and P transport. Soil health BMPs can be adopted by Mid-South producers on silt loam textured soils without adversely affecting economic returns, while subsequently relieving groundwater supply issues and improving surface water quality.

Table 1. Total specified costs in dollars ha^{-1} for soybeans grown in a study conducted in 2015 at Stoneville, MS on a Bosket very fine sandy loam and Dubbs silt loam.

Treatment*	Total specific costs
	---------- $ ----------
CT	335.91
MT	319.37
MT/RC	338.70
NT/FS	306.68

* Total specified costs include direct costs and exclude land rent, general farm overhead and returns to management.

Table 2. Soybean yield components and soybean grain yield for a study conducted in 2015 at Stoneville, MS on a Bosket very fine sandy loam and Dubbs silt loam. Parameters were not statistically different at $P \le 0.05$.

Treatment*	Plants m^{-1}	Plant Height	Nodes $Plant^{-1}$	Pods $Plant^{-1}$	Wt. Pods	Wt. Seed	Wt. 1K Seed	Yield
		----- cm -----			-------------------- g ---------------------			-- kg ha^{-1} --
CT	28	95.61	17	41	542	370.6	130.3	4542
MT	27	95.93	19	46	604	412.4	136.1	4624
MT/RC	26	103.74	18	53	488	394.3	131.2	4649
NT/FS	23	86.85	17	51	519	347.6	134.7	4729

* CT, conventional tillage; MT, minimum tillage; MT/RC, minimum tillage with cereal rye (*Secale cereale*) cover crop; NT/FS, no-tillage/furrow sweep.

Table 3. Net return above specified costs and adjusted for weed control, calculated irrigation efficiency, and both weed control and irrigation efficiency in dollars ha^{-1} for a study conducted in 2015 in Stoneville, MS on a Bosket very fine sandy loam and a Dubbs silt loam. Parameters were not significantly different at P ≤ 0.05.

Treatment*	Economic Return	Adjusted for weed control	Adjusted for irrigation efficiency	Adjusted for weed control and irrigation efficiency
	$ ha^{-1}			
CT	724.37	724.37	696.11	696.11
MT	793.07	793.07	723.68	723.68
MT/RC	724.47	333.84	709.05	840.34
NT/FS	859.02	859.02	846.17	846.17

* CT, conventional tillage; MT, minimum tillage; MT/RC, minimum tillage with cereal rye (*Secale cereale*) cover crop; NT/FS, no-tillage/furrow sweep.

Table 4. Irrigation application efficiency, furrow advance time, infiltration volume, and runoff volume for a study conducted on a Bosket very fine sandy loam and Dubbs silt loam at Stoneville, MS in 2015.

Treatment*	IAE**	Furrow Advance Time	Infiltration Volume	Runoff Volume
	%	Min	L	L
CT	69 b***	149 b	53,438 b	29,472 b
MT	44 c	119 b	33,950 c	48,960 a
MT/RC	82 a	246 a	66,714 ab	16,197 bc
NT/FS	87 a	246 a	71,195 a	11,716 c

* CT, conventional tillage; MT, minimum tillage; MT/RC, minimum tillage with cereal rye (*Secale cereale*) cover crop; NT/FS, no-tillage/furrow sweep.
** IAE, irrigation application efficiency
*** Values in a column followed by the same letter are not significantly different at P ≤ 0.05

Table 5. Off-site transport of total solids, filtered solids, and suspended solids for a study conducted on a Bosket very fine sandy loam and Dubbs silt loam at Stoneville, MS in 2015.

Treatment*	Total Solids	Filtered Solids	Suspended Solids
	kg ha^{-1}		
CT	109.84 a**	52.21 b	57.24 a
MT	152.71 a	93.27 a	59.44 a
MT/RC	38.19 b	30.53 bc	30.53 b
NT/FS	27.85 b	21.24 c	21.24 b

* CT, conventional tillage; MT, minimum tillage; MT/RC, minimum tillage with cereal rye (*Secale cereale*) cover crop; NT/FS, no-tillage/furrow sweep.
** Values in a column followed by the same letter are not significantly different at P ≤ 0.05

Table 6. Off-site transport of total Kjeldahl N, NH_4^+-N, NO_2^--N, and NO_3^--N for a study conducted on a Bosket very fine sandy loam and Dubbs silt loam at Stoneville, MS in 2015.

Treatment*	TKN**	NH_4^+-N	NO_2^--N	NO_3^--N
	-------------------------------	Kg ha^{-1}	-------------------------------	
CT	0.3441 ab***	0.0136	0.0010 b	0.007 b
MT	0.4503 a	0.0282	0.0045 a	0.045 a
MT/RC	0.2123 bc	0.0316	0.0029 ab	0.017 b
NT/FS	0.1465 c	0.0119	0.0017 b	0.015 b

* CT, conventional tillage; MT, minimum tillage; MT/RC, minimum tillage with cereal rye (*Secale cereale*) cover crop; NT/FS, no-tillage/furrow sweep.
** TKN, total Kjeldahl N
*** Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

Table 7. Off-site transport of total P, ortho-phosphate, and total dissolved organic carbon for a study conducted on a Bosket very fine sandy loam and Dubbs silt loam at Stoneville, MS in 2015.

Treatment*	Total P	Ortho-phosphate
	------------------------ kg ha^{-1}	------------------------
CT	0.0345 B***	0.0263 BC
MT	0.0728 A	0.0564 A
MT/RC	0.0384 B	0.0357 B
NT/FS	0.0245 B	0.0220 C

* CT, conventional tillage; MT, minimum tillage; MT/RC, minimum tillage with cereal rye (*Secale cereale*) cover crop; NT/FS, no-tillage/furrow sweep.
** TDOC, total dissolved organic carbon
*** Values in a column followed by the same letter are not significantly different at $P \leq 0.05$

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