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

C.J. Bryant, L.J. Krutz, D. Reynolds, M.A. Locke, B. Golden, T. Irby, L. Falconer, R.W. Steinriede

ABSTRACT

Soil "health" best management practices (BMPs) have potential to improve agricultural production systems when applied properly, but few Midsouth 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 offsite 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 had 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; i.e., 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 Midsouthern US is one region where soil health programs have not seen wide acceptance or implementation, yet could have a significant impact on production practices. Midsouth 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 prominent irrigation practice in the Midsouth. 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 at Stoneville, Miss., 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 costs for 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 improvement, 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 Midsouth. While this system may maintain 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), thus 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 on 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, Miss. 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 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. Cereal 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 all plots was conducted on May 1. 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 14 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. The 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:

$$\text{IAE} = \frac{V_A - V_R}{V_A} \text{ x } 100$$

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 on calculated efficiency percentages and adjusting volume of irrigation water applied.

RESULTS AND DISCUSSION

Soybean Yield and Yield Components.

In 2015, soybean yield and yield components were not different among treatments ($P \geq 0.1509$) (Table 2). Conversely, in 2016, treatment had a significant effect on soybean grain yield ($P = 0.043$) (Table 8). Conventional tillage/No cover yielded significantly greater than all other treatments, except for MT/RC, which was not different from any other treatment.

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 4 of 9 years; however, these 4 years were split evenly between conventional tillage and no-tillage each having significantly higher yields for 2 of the 4 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 Midsouth 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.

In 2015, 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 were not different among treatments ($P \geq 0.243$) (Table 3). Conversely, in 2016, treatment had a significant effect on net return ($P = 0.005$), where conventional tillage/No Cover had the highest net return (Table 8). More data are required before we can determine if the 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 2015.

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 for 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.

Irrigation Application Efficiency 2015.

In year two, treatment did not significantly affect IAE ($P = 0.45$), infiltration volume ($P = 0.45$), or runoff volume ($P = 0.45$) (Table 9). Treatment did significantly affect furrow advance time ($P > 0.01$) (Table 9). Minimum tillage/Tillage radish and MT/NC reduced furrow advance time 97% and 78.5%, respectively, compared to the highest treatment ZT/NC.

Sediment Transport.

In 2015, 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.

In year two, treatment had a significant effect on transported total solids ($P = 0.03$) (Table 10), with CT/NC, MT/RC, ZT/NC, and ZT/TR reducing transported total solids 100-147% when compared to the highest treatment MT/TR. Treatment had a significant effect on filtered solids ($P = 0.04$), with MT/SS, CT/NC, ZT/NC, and ZT/TR reducing filtered solids 54-113% compared to the highest treatment MT/NC. Treatment had a significant effect on suspended solids ($P = 0.05$). Minimum tillage/Tillage radish had significantly more suspended solids than all other treatments.

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^- was not different between MT/RC, NT/FS, and CT, while losses from MT were 6.4-fold greater than those from 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 were 3.4-fold greater than from 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.

In year two, treatment had a significant effect on TKN ($P = 0.03$) (Table 11), with MT/NC having significantly greater effect than all other treatments. Treatment did not significantly effect ammonium amount ($P = 0.06$). Zone tillage/No cover possessed the highest amounts of nitrite ($P > 0.01$) and nitrate ($P = 0.03$).

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.

In year two, treatment significantly effected total P ($P < 0.01$) and Ortho-phosphate ($P = 0.02$) (Table 12).

CONCLUSIONS

The objectives of this study were 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 Midsouth without adversely affecting soybean yield components, yield, or economic return above specified costs. Irrigation application efficiency can be improved to efficiencies similar to that of overhead sprinkler systems on silt loam textured soils by implementing no-tillage or rye cover crops. 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 offsite N and P transport. Soil health BMPs can be adopted by Midsouth 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 for soybeans grown in a study conducted in 2015 at Stoneville, Miss. on Bosket very fine sandy loam and Dubbs silt loam soils.

Treatment*	Total specific costs
	$/ha
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 from a study conducted in 2015 at Stoneville, MS on Bosket very fine sandy loam and Dubbs silt loam soils. Parameters were not statistically different at P ≤ 0.05.

Treatment*	Plants/m	Plant Height	Nodes/plant	Pods/plant	Wt. Pods	Wt. Seed	Wt./1000 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 from a study conducted in 2015 at Stoneville, Miss. on Bosket very fine sandy loam and Dubbs silt loam soils. Parameters were not significantly different at P ≤ 0.05.

Treatment*	Net Return	Adjusted for weed control	Adjusted for irrigation efficiency	Adjusted for weed control and irrigation efficiency
	--------------------	--------------------	$/ha --------------------	--------------------
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 from a study conducted on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, Miss. in 2015.

Treatment*	IAE**	Furrow Advance Time	Infiltration Volume	Runoff Volume
	%	min.	-------------------- 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. Offsite transport of total solids, filtered solids, and suspended solids from a study conducted on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, Miss. in 2015.

Treatment*	Total Solids	Filtered Solids	Suspended Solids
	----------------------------------	kg/ha	----------------------------------
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. Offsite transport of total Kjeldahl N, NH_4^+-N, NO_2^--N, and NO_3^--N from a study conducted on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, Miss. in 2015.

Treatment*	TKN**	NH_4^+-N	NO_2^--N	NO_3^--N
	--	kg/ha	--	
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 ≤ 0.05

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

Treatment*	Total P	Ortho-phosphate
	------------------------ kg/ha	------------------------
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 ≤ 0.05

Table 8. Year two soybean grain yield and net returns from a study conducted in 2016 at Stoneville, Miss. on Bosket very fine sandy loam and Dubbs silt loam soils.

Treatment*	Yield (kg/ha)	Net Return ($/ha)
CT/NC	4333 a	359.62 a
MT/NC	3735 b	276.38 b
MT/RC	3993 ab	291.88 b
MT/SS	3872 b	295.90 ab
MT/TR	3596 b	199.97 c
ZT/NC	3645 b	288.37 b
ZT/TR	3654 b	233.08 bc

* CT, conventional tillage; MT, minimum tillage; ZT, zone tillage; RC, cereal rye (*Secale cereale*) cover crop; TR, tillage radish (*Raphanus sativus*) cover crop.
**Values in a column followed by the same letter are not significantly different at P ≤ 0.05

Table 9. Year two results for irrigation application efficiency, furrow advance time, infiltration volume, and runoff volume from a study conducted on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, Miss. in 2016.

Treatment*	IAE**	Furrow Advance Time	Infiltration Volume	Runoff Volume
	%	min.	---------------------L	--------------------
CT/NC	65.6	108 cd	54,365	28,545
MT/NC	28.7	98 d	23,825	59,086
MT/RC	59.4	154 ab	49,282	33,628
MT/SS	64.1	121 bcd	53,119	29,791
MT/TR	45.5	89 d	37,706	45,205
ZT/NC	62.4	175 a	51,759	31,151
ZT/TR	52.3	137 bc	43,391	39,519

* CT, conventional tillage; MT, minimum tillage; ZT, zone tillage; RC, cereal rye (*Secale cereale*) cover crop; TR, tillage radish (*Raphanus sativus*) cover crop.
**IAE, irrigation application efficiency
***Values in a column followed by the same letter are not significantly different at P ≤ 0.05

Table 10. Year two results for offsite transport of total solids, filtered solids, and suspended solids from a study conducted on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, Miss. in 2016.

Treatment*	Total Solids	Filtered Solids	Suspended Solids
	----------kg/ha----------		
CT/NC	46.5 c	38.4 bc	8.4 b
MT/NC	102.8 ab	78.7 a	24.1 b
MT/RC	47.7 c	43.9 bc	3.7 b
MT/SS	62.7 bc	36.9 c	25.8 b
MT/TR	114.9 a	61.6 ab	53.4 a
ZT/NC	48.1 c	40.5 bc	7.6 b
ZT/TR	57.4 c	51.1 bc	6.4 b

* CT, conventional tillage; MT, minimum tillage; ZT, zone tillage; RC, cereal rye (*Secale cereale*) cover crop; TR, tillage radish (*Raphanus sativus*) cover crop.
**Values in a column followed by the same letter are not significantly different at P ≤ 0.05

Table 11. Year two results for offsite transport of total Kjeldahl N, NH_4^+-N, NO_2^--N, and NO_3^--N from a study conducted on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, MS in 2016.

Treatment*	TKN**	NH_4^+-N	NO_2^--N	NO_3^--N
	----------kg/ha----------			
CT/NC	0.24 b	0.03	0.0012 d	0.0067 c
MT/NC	0.69 a	0.164	0.0069 ab	0.039 abc
MT/RC	0.33 b	0.051	0.0033 cd	0.0142 c
MT/SS	0.26 b	0.041	0.0018 d	0.0052 c
MT/TR	0.41 b	0.067	0.0029 cd	0.0228 bc
ZT/NC	0.36 b	0.072	0.0092 a	0.0719 a
ZT/TR	0.38 b	0.053	0.0054 bc	0.0534 ab

* CT, conventional tillage; MT, minimum tillage; ZT, zone tillage; RC, cereal rye (*Secale cereale*) cover crop; TR, tillage radish (*Raphanus sativus*) cover crop.
** TKN, total Kjeldahl N
***Values in a column followed by the same letter are not significantly different at P ≤ 0.05

Table 12. Year two results for offsite transport of total P, and ortho-phosphate form a study conducted on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, MS in 2016.

Treatment*	Total P	Ortho-phosphate
	----------kg/ha----------	
CT/NC	0.019 c	0.026 c
MT/NC	0.063 ab	0.087 a
MT/RC	0.045 bc	0.068 ab
MT/SS	0.019 c	0.027 c
MT/TR	0.037 bc	0.051 bc
ZT/NC	0.077 a	0.079 ab
ZT/TR	0.049 b	0.056 abc

* CT, conventional tillage; MT, minimum tillage; ZT, zone tillage; RC, cereal rye (*Secale cereale*) cover crop; TR, tillage radish (*Raphanus sativus*) cover crop.
**Values in a column followed by the same letter are not significantly different at P ≤ 0.05

REFERENCES

Acuna, J.C.M., and M.B. Villamil. 2014. Short-Term Effects of Cover Crops and Compaction on Soil Properties and Soybean Production in Illinois. Agronomy Journal 106:860-870.

American Public Health Association. 1997a. Standard Method 2540 D: Total Suspended Solids Dried at 103-105^{o}C. APHA, Washington, DC.

American Public Health Association. 1997b. Standard Method 4500-NH_3 Nitrogen (Ammonia) F: Phenate Method. APHA, Washington, DC.

American Public Health Association. 1997c. Standard Method 4500-P Phosphorus E: Ascorbic Acid Method. APHA, Washington, DC.

American Public Health Association. 1997d. Standard Method 2540 Solids C: Total Dissolved Solids Dried at 180^{o}C. APHA, Washington, DC.

American Public Health Association. 2000a. Standard Method 4500-NO_3^- Nitrogen (Nitrate) E: Cadmium Reduction Method. APHA, Washington, DC.

American Public Health Association.2000b. Standard Method 4500-NO_2 Nitrogen (Nitrite): Colorimetric Method. APHA, Washington, DC.

Balkcom, K.S., J.N. Shaw, D.W. Reeves, C.H. Burmester, and L.M. Curtis. 2007. Irrigated Cotton Response to Tillage Systems in the Tennessee Valley. Journal of Cotton Science 11:2-11.

Bertol, I., F.L. Engel, A.L. Mafra, O.J. Bertol, and S.R. Ritter. 2007. Phosphorus, Potassium and Organic Carbon Concentrations in Runoff Water and Sediments Under Different Soil Tillage Systems during Soybean Growth. Soil and Tillage Research 94:142-150.

Blanco-Canqui, H., J.D. Holman, A.J. Schlegel, J. Tatarko, and T.M. Shaver. 2013. Replacing Fallow with Cover Crops in a Semiarid Soil: Effects on Soil Properties. Soil Science Society of America Journal 77:1026-1034.

Clark, A.J., J.J. Meisinger, A.M. Decker, and F.R. Mulford. 2007. Effects of a Grass-Selective Herbicide in a Vetch-Rye Cover Crop System on Corn Grain Yield and Soil Moisture. Agronomy Journal 99:43-48.

Dabney, S.M., J.A. Delgado and D.W. Reeves. 2001. Using Winter Cover Crops to Improve Soil and Water Quality. Communication in Soil Science and Plant Analysis 32(7-8):1221-1250.

Delate, K., D. Cwach, and C. Chase. 2011. Organic No-Tillage System Effects on Soybean Corn and Irrigated Tomato Prodcution and Economic Performance in Iowa, USA. Renewable Agriculture and Food Systems 27:49-59.

DeLaune, P.B., J.W. Sij, S.C. Park, and L.J. Krutz. 2012. Cotton Production as Affected by Irrigation Level and Transitioning Tillage Systems. Agronomy Journal 104:991-995.

Endale, D.M., H.H. Schomberg, D.S. Fisher, M.B. Jenkins, R.R. Sharpe, and M.L. Cabrera. 2008. No-Till Corn Productivity in a Southeastern United States Ultisol Amended with Poultry Litter. Agronomy Journal 100:1401-1408.

Fageria, N.K., V.C. Baligar, and B.A. Bailey. 2005. Role of Cover crops in Improving Soil and Row Crop Productivity. Communications in Soil Cience and Plant Analysis 36:2733-2757.

Franklin, D.H., C.C. Truman, T.L. Potter, D.D. Bosch, T.C. Strickland, M.B. Jenkins, and R.C. Nuti. 2012. Nutrient Losses in Runoff from Conventional and No-till Pearl Millet on Pre-wetted Ultisols Fertilized with Broiler Litter. Agricultural Water Management 113:38-44.

Gabriels, D., R. Horn, M.M. Villagra, and R. Hartmann. 1997. Assessment, Prevention, and Rehabilitation of Soil Structure Caused by Soil Surface Sealing, Crusting, and Compaction. In: R. Lal, W.H. Blum, C. Valentine, B.A. Stewart, editors, Methods for Assessment of Soil Degradation. CRC Press, Boca Raton, NY. p. 129-165.

Gulick, S.H., D.W. Grimes, D.S. Munk, and D.A. Goldhamer. 1994. Cover-Crop-Enhanced Water Infiltration of a Slowly Permeable Fine Sandy Loam. Soil Science Society of America Journal 58:1539-1546.

Hartwig, R.O., and J.M. Laflen. 1978. A Meterstick Method for Measuring Crop Residue Cover [in Preventing Soil Erosion]. Journal of Soil and Water Conservation 33:90-91.

Kaspar, T.C., J.K. Radke, and J.M. Laflen. 2001. Small Grain Cover Crops and Wheel Traffic Effects on Infiltration, Runoff, and Erosion. Journal of Soil and Water Conservation 56:160-164.

Kornecki, T.S., F.J. Arriaga, and A.J. Price. 2012. Roller Type and Operating Speed Effects on Rye Termination Rates, Soil Moisture, and Yield of Sweet Corn in a No-Till System. HortScience 47:217-223.

Lado, M., A. Paz, and M. Ben-Hur. 2004. Organic Matter and Aggregate Size Interactions in Infiltration, Seal Formation, and Soil Loss. Soil Science Society of America Journal 68:935-942.

Lahmar, R. 2010. Adoption of Conservation Agriculture in Europe Lessons of the KASSA Project. Land Use Policy 27:4-10.

Lampurlanes, J., and C. Cantero-Martinez. 2006. Hydraulic Conductivity, Residue Cover and Soil Surface Roughness under Different Tillage Systems in Semiarid Conditions. Soil and Tillage Research 85:13-26.

Locke, M.A., L.J. Krutz, R.W. Steinriede, Jr., and S. Testa, III. 2015. Conservation Management Improves Runoff Water Quality: Implications for Environmental Sustainability in a Glyphosate-Resistant Cotton Production System. Soil Science Society of America Journal 79:660-671.

Locke, M.A., R.M. Zablotowicz, P.J. Bauer, R.W. Steinriede, and L.A. Gaston. 2005. Conservation Cotton Production in the Southern United States: Herbicide Dissipation in Soil and Cover Crops. Weed Science 53:717-727.

Merten, G.H., A.G. Araujo, R.C.M. Biscaia, G.M.C. Barbosa, and O. Conte. 2015. No-till Surface Runoff and Soil Losses in Southern Brazil. Soil and Tillage Research 152:85-93.

Olson, K.R., S.A. Ebelhar, and J.M. Lang. 2010. Cover Crop Effects on Crop Yields and Soil Organic Carbon Content. Soil Science 175:89-98.

Price, A.J., F.J. Arriaga, R.L. Raper, K.S. Balkcom, T.S. Komecki, and D.W. Reeves. 2009. Comparison of Mechanical and Chemical Winter Cereal Cover Crop Termination Systems and Cotton Yield in Conservation Agriculture. Journal of Cotton Science 13:238-245.

Raper, R.L., D.W. Reeves, C.H. Burmester, and E.B. Schwab. 2000. Tillage Depth, Tillage Timing, and Cover Crop Effects on Cotton Yield, Soil Strength, and Tillage Energy Requirements. Applied Engineering in Agriculture 16(4):379-386.

Reddy, K.N., R.M. Zablotowicz, M.A. Locke, and C.H. Koger. 2003. Cover Crop, Tillage, and Herbicide Effects on Weeds, Soil Properties, Microbial Populations, and Soybean Yield. Weed Science 51:987-994.

Ruffo, M.L., D.G. Bullock, and G.A. Bollero. 2004. Soybean Yield as Affected by Biomass and Nitrogen Uptake of Cereal Rye in Winter Cover Crop Rotations. Agronomy Journal 96:800-805.

Smith, A.N., S.C. Reberg-Horton, G.T. Place, A.D. Meijer, C. Arellano, and J.P. Mueller. 2011. Rolled Rye Mulch for Weed Suppression in Organic No-Tillage Soybeans. Weed Science 59:224-231.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [05/14/15]

Tyler, H.H., S.L. Warren, and T.E. Bilderback. 1996. Cyclic Irrigation Increases Irrigation Application Efficiency and Decreases Ammonium Losses[1]. Journal of Environmental Horticulture 14(4):194-198.

Watts, D.B., and H.A. Torbert. 2011. Long-Term Tillage and Poultry Litter Impacts on Soybean and Corn Grain Yield. Agronomy Journal 103:1479-1486.

Yohannes, F., and T. Tadesse. 1998. Effect of Drip and Furrow Irrigation and Plant Spacing on Yield of Tomato and Dire Dawa, Ethiopia. Agricultural Water Management 35:201-207.

Yoo, K.H., J.T. Touchton, and R.H. Walker. 1989. Effect of Conservation-Tillage Systems of Cotton on Surface Runoff and Its Quality. Journal of Agricultural Engineering Research 44:289-299.

Yoo, K.H., J.T. Touchton, and R.H. Walker. 1988. Runoff, Sediment and Nutrient Losses from Various Tillage Systems of Cotton. Soil and Tillage Research 12:13-24.