MISSISSIPPI SOYBEAN PROMOTION BOARD
PROJECT NO. 52-2017 (YEAR 3)
2017 FINAL REPORT

Title: Agronomic and Irrigation Efficiency Impacts of Conservation Tillage and Cover Crops in Soybean Production: Three Year Results

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EXECUTIVE SUMMARY

The potential improvements to agricultural production systems from properly applied soil health best management practices (BMPs) are numerous; however, few Midsouthern US producers have adopted production systems to promote soil health.

This study was conducted to determine the effect of conservation tillage (conventional tillage, reduced tillage, zone tillage) and cover crops [cereal rye, tillage radish, no cover crop] with conservation tillage on soybean grain yield, net return above specified costs, irrigation application efficiency, and agrochemical transport.

Seven treatments included 1) conventional tillage/no cover (CT/NC), 2) minimum tillage/no cover (MT/NC), 3) minimum tillage/rye cover (MT/RC), 4) minimum tillage/tillage radish (MT/TR), 5) minimum tillage/sub-soiling (MT/SS), 6) zone tillage/no cover (ZT/NC), and 7) zone tillage/tillage radish (ZT/TR). Experimental units were planted to soybean and were instrumented to mass balance the offsite transport of water, sediment, and agrochemicals. Year one was a transitional period where all treatments were not included; therefore, year one results are presented individually and year two and three results are averaged across years.

Soybean grain yield, irrigation application efficiency, and net returns were not different among treatments in year one. Averaged across years two and three, soybean grain yield in CT/NC was greater than for all conservation practice treatments except MT/RC, which was no different from any other conservation practice ($P = 0.0408$). In year one irrigation application efficiency decreased in the order of ZT (87%) = MT/RC (82%) > CT (69%) > MT (44%). Irrigation application efficiency was not affected by treatment in year two ($P \geq 0.4286$). Nutrient and sediment losses were different among treatments in year one but not year two ($P \leq 0.0534$). Net returns above specified costs were not different in year one ($P = 0.1692$); however, averaged across years two and three, MT/SS and CT/NC increased net returns compared to MT/NC, MT/RC, and MT/TR ($P = 0.0014$). When compared to the current regional standard of MT/NC, the inclusion of soil health BMPs had no effect on soybean grain yield or net returns above specified costs in this short-term experiment.

Some soil health BMPs which include CC or conservation tillage may be applied to silt loam soils in the Midsouth without adversely affecting soybean grain yield. However, these systems must be carefully evaluated on a field-by-field basis since some negative soybean grain yield responses were measured. Inclusion of CC in a reduced tillage system reduced net returns compared to a conventional tillage or MT/SS system, but did not differ from current regional practices.

Benefits to IAE and runoff volumes varied by years, indicating that CC and conservation tillage systems may not increase IAE in every year, but they also will not decrease the efficiency of furrow irrigation. Moreover, adoption of zone tillage or a cereal rye CC can greatly reduce cumulative sediment losses. The benefits from soil health BMPs on N and P transport is sporadic and may have no effect in some years.

Inclusion of soil health BMPs on silt loam soils in Midsouth soybean production systems may be adopted without negatively affecting soybean grain yield or net returns but should be carefully evaluated on a field-by-field basis.

ABSTRACT

The potential improvements to agricultural production systems from properly applied soil health best management practices are numerous; however, few Midsoutheern US producers have adopted production systems to promote soil health.

This study was conducted to determine the effect of conservation tillage (conventional tillage, reduced tillage, zone tillage) and cover crops [cereal rye (*Secale cereal* L.), tillage radish (*Raphanus sativus* L.), no cover crop] with conservation tillage on soybean (*Glycine max*) grain yield, net return above specified costs, irrigation application efficiency, and agrochemical transport.

Seven treatments included 1) conventional tillage/no cover (CT/NC), 2) minimum tillage/no cover (MT/NC), 3) minimum tillage/rye cover (MT/RC), 4) minimum tillage/tillage radish (MT/TR), 5) minimum tillage/sub-soiling (MT/SS), 6) zone tillage/no cover (ZT/NC), and 7) zone tillage/tillage radish (ZT/TR) The treatments were arranged in a randomized complete block design with three replications. Experimental units (8.13 m wide by 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. Year one was a transitional period where all treatments were not included; therefore, year one results are presented individually and year two and three results are averaged across years.

Soybean grain yield, irrigation application efficiency, and net returns were not different among treatments in year one. Averaged across years two and three, soybean grain yield in CT/NC was greater than for all conservation practice treatments except MT/RC, which was no different from any other conservation practice ($P = 0.0408$). In year one irrigation application efficiency decreased in the order of ZT (87%) = MT/RC (82%) > CT (69%) > MT (44%). Irrigation application efficiency was not affected by treatment in year two ($P \geq 0.4286$). Nutrient and sediment losses were different among treatments in year one but not year two ($P \leq 0.0534$). Net returns above specified costs were not different in year one ($P = 0.1692$); however, averaged across years two and three, MT/SS and CT/NC increased net returns compared to MT/NC, MT/RC, and MT/TR ($P = 0.0014$). When compared to the current regional standard of MT/NC, the inclusion of soil health BMP's had no effect on soybean grain yield or net returns above specified costs in this short-term experiment.

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 and reduce erosion and offsite agrochemical transport; that is, decrease soil disturbance, increase soil coverage, and promote 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. Midsouthern US producers are skeptical of soil health programs due to associated production limitations, both perceived and actual. Irrigated agriculture in the region 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), which subsequently increases 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 BMP's, 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 such as raindrop impact that induce crusting (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, cereal rye, tillage radish) and tillage (conventional tillage, reduced tillage, zone tillage, sub-soiling) on soybean grain yield, net returns, 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 from 2015-2017. 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 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 a randomized complete block design. Treatments included 1) minimum tillage/ no cover (MT/NC), 2) minimum tillage/cereal rye cover (MT/RC), 3) zone tillage/no cover (ZT/NC), and 4) conventional tillage/no cover (CT/NC). Beginning in year two three additional treatments of 5) minimum tillage/tillage radish cover (MT/TR), 6) minimum tillage/sub-soiling (MT/SS), and 7) zone tillage/tillage radish cover (ZT/TR) were added. Tillage operations were conducted as follows: 1) minimum tillage treatments were disked twice followed by bed formation in the fall after harvest; 2) zone tillage treatments were planted flat, and one pass was made with a sweep plow just prior to irrigation initiation for furrow creation; 3) 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; and 4) one pass was made across MT and CT, with the exception of MT/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. Burndown of all plots was conducted on May 1, April 26, and May 8 in 2015, 2016, and 2017, respectively. Tillage radish was chemically desiccated on February 10, and March 21, respectively, in 2016 and 2017. 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 14, May 11, and May 9 in 2015, 2016, and 2017, respectively, 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 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. Percentage ground cover was determined 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 each measured plot.

The middle six rows of each plot were mechanically harvested and seeds were 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:

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

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 of 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 returns above specified costs (Table 1). Enterprise budgets were developed using Mississippi State University Delta Planning budgets for 2016, 2017, and 2018. Soybean prices were based on current cash value at Greenville, MS at the time of harvest. Results were analyzed using the MIXED 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

Soybean grain yield was not influenced by conservation tillage or a cereal rye cover crop during the year one transition period (*P* = 0.8263). When averaged across years two and three, conservation practices did alter soybean grain yield (*P* = 0.0408; Table 2). Conventional tillage/no cover was no different than MT/SS or MT/RC, but was greater than ZT/TR, MT/NC, ZT/NC, and MT/TR. Minimum tillage/sub-soiling was greater than only MT/TR and no other treatments were different from one another.

These results agree with similar studies which reported no differences in soybean grain yield following a cereal rye cover crop and reductions in a no-tillage system, which would be similar to the zone tillage treatments (Delate et al., 2011; Reddy et al., 2003; Ruffo et al., 2004; Smith et al., 2011). Long-term tillage studies have reported varied results in which soybean grain yield was not affected by tillage in some years and split evenly between no-tillage and conventional tillage in years where differences were observed (Watts and Torbert, 2011). These data indicate that a soil health BMP should have no effect on soybean grain yield in the Midsouth region, USA, compared to the current regional standard of MT/NC.

Economic Analysis

Net returns above specified costs were not influenced by conservation tillage or a cereal rye cover crop during the year one transition period (*P* = 0.1692). However, net returns were affected by treatments when averaged across years two and three (*P* = 0.0019; Table 3). Net returns above specified costs for MT/SS, CT/NC, and ZT/NC were greater than those for MT/RC and MT/TR, but were no different from those for ZT/TR, and MT/NC. Similarly, ZT/TR and MT/NC were not different from one another, but were greater than those for MT/TR, while MT/RC and MT/TR net returns were not different from one another. These data indicate that the additional costs associated with CC planting and desiccation can have a negative impact on net returns. Inclusion of a cereal rye CC in this system contained one additional cost of planting only since desiccation occurred simultaneously with spring burndown of all no CC treatments. Conversely, tillage radish contains associated planting costs similar to cereal rye but must be desiccated with herbicide in some years. This herbicide application is generally too early in the season to be the normal spring burndown, resulting in two herbicide applications prior to planting. However, the fact that ZT/TR was not different from MT/SS indicates that costs associated with CC planting and desiccation can be recouped through reductions in tillage. Compared to the current regional standard of MT/NC, no soil health BMPs affected net returns.

Irrigation Application Efficiency

Data for irrigation application efficiency in 2017 are still being processed in the lab at this time; therefore, the following data cover the first two years of the project. 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 ZT/NC increased furrow advance times by at least 65% relative to CT and MT (Table 4). Similarly, furrow advance times were 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. Zone tillage/no cover 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 ZT/NC was at least 13% greater than for CT and MT ($P = 0.0002$) (Table 4). Irrigation application efficiencies calculated for MT/RC and ZT/NC 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 soil in the Midsouth.

In year two, treatment did not significantly affect IAE ($P = 0.45$), infiltration volume ($P = 0.45$), or runoff volume ($P = 0.45$) (Table 5). Treatment did significantly affect furrow advance time ($P > 0.01$) (Table 5). Minimum tillage/Tillage radish and MT/NC reduced furrow advance time 97% and 78.5%, respectively, compared to the highest treatment ZT/NC.

Offsite Transport

Transport data for 2017 are also still being processed in the lab. The following results are presented for years one and two individually.

Sediment Transport

In 2015, soil health BMPs reduced offsite sediment transport ($P \leq 0.0003$). Relative to CT and MT, MT/RC and NT/FS reduced cumulative sediment loss by 65% (Table 6). 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 from silt loam soils through implementation of BMPs that promote soil health.

In year two, treatment had a significant effect on transported total solids ($P = 0.03$) (Table 6), with CT/NC, MT/RC, ZT/NC, and ZT/TR reducing transported total solids 100-147% compared to treatment MT/TR, which had the highest value for transported solids. 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 from MT, MT/RC, and CT (Table 7). Ammonium losses were not different among treatments ($P = 0.0828$). The transport of NO_2^- and NO_3^- were not different among 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 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 offsite 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 from silt loam soils.

In year two, treatment had a significant effect on TKN ($P = 0.03$) (Table 7), with MT/NC having significantly greater TKN than all other treatments. Treatment did not significantly affect ammonium amount ($P = 0.06$). Zone tillage/No cover possessed the highest amounts of nitrite ($P > 0.01$) and nitrate ($P = 0.03$).

Phosphorous Transport

Total P and ortho-phosphate transport differed among soil health BMPs (Table 8). 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. Offsite 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 from CT than from no-tillage (Franklin et al., 2012). These data indicate that soil health BMPs will not reduce the offsite transport of TP and ortho-phosphate on silt loam soils. In year two, treatment significantly affected total P ($P < 0.01$) and Ortho-phosphate ($P = 0.02$) (Table 8).

CONCLUSION

The objective of this study was to determine the effect of cover crop (no cover, cereal rye, tillage radish) and tillage (conventional tillage, reduced tillage, zone tillage, sub-soiling) on soybean grain yield, net returns, irrigation application efficiency, and agrochemical transport. Some soil health BMPs which include CC or conservation tillage may be applied to silt loam soils in the Midsouth without adversely affecting soybean grain yield. However, these systems must be carefully evaluated on a field-by-field basis since some negative soybean grain yield responses were measured. Inclusion of CC in a reduced tillage system reduced net returns compared to a conventional tillage or MT/SS system, but did not differ from current regional practices.

Benefits to IAE and runoff volumes varied by years, indicating that CC and conservation tillage systems may not increase IAE in every year, but they also will not decrease the efficiency of furrow irrigation. Moreover, adoption of zone tillage or a cereal rye CC can greatly reduce cumulative sediment losses. The benefits from soil health BMPs on N and P transport is sporadic and may have no effect in some years. Inclusion of soil health BMPs on silt loam soils in Midsouth soybean production systems may be adopted without negatively affecting soybean grain yield or net returns but should be carefully evaluated on a field-by-field basis.

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Table 1. Total specified costs in dollars ha^{-1} for soybeans grown from 2015-2017 in a conservation tillage and cover crop study conducted at Stoneville, MS on Bosket very find sandy loam and Dubbs silt loam soils.

Treatment	2015	2016	2017
	---------- $ ha^{-1} ----------		
CT/NC[†]	335.91	258.94	277.76
MT/NC	319.37	257.06	276.10
MT/SS	—	257.06	276.10
MT/RC	360.92	301.16	334.26
MT/TR	—	313.31	333.44
ZT/NC	306.68	231.95	255.20
ZT/TR	—	288.20	308.30

[†] CT/NC = Conventional Tillage/No Cover; MT/NC = Minimum Tillage/No Cover; MT/SS = Minimum Tillage/Sub-soiling; MT/RC = Minimum Tillage/ Rye Cover; MT/TR = Minimum Tillage/Tillage Radish; ZT/NC = Zone Tillage/No Cover; ZT/TR = Zone Tillage/Tillage Radish

Table 2. Soybean grain yield from a conservation tillage and cover crop study conducted from 2015-2017 at Stoneville, MS on Bosket very fine sandy loam and Dubbs silt loam soils. Information presented is year one transition period and years two and three averaged.

Treatment	Year One	Years 2&3 Average
	---------- kg ha^{-1} ----------	
CT/NC[†]	4542[§]	3911 a[‡]
MT/NC	4624	3481 bc
MT/SS	—	3738 ab
MT/RC	4649	3621 abc
MT/TR	—	3400 c
ZT/NC	4729	3475 bc
ZT/TR	—	3591bc

[†] CT/NC = Conventional Tillage/No Cover; MT/NC = Minimum Tillage/No Cover; MT/SS = Minimum Tillage/Sub-soiling; MT/RC = Minimum Tillage/ Rye Cover; MT/TR = Minimum Tillage/Tillage Radish; ZT/NC = Zone Tillage/No Cover; ZT/TR = Zone Tillage/Tillage Radish

[§] Numbers not followed by a letter are not different at the $P \leq 0.05$ level.

[‡] Numbers followed by the same letter are not different at the $P \leq 0.05$ level.

Table 3. Net returns above specified costs for a conservation tillage and cover crop study conducted from 2015-2017 in Stoneville, MS on Bosket very fine sandy loam and Dubbs silt loam soils. Information presented is year one transition period and years two and three averaged.

Treatment	Year One	Years 2&3 Average
	------------------------ $ ha^{-1}	---------------------------
CT/NC†	724.37§	706.63 a‡
MT/NC	793.07	631.61 ab
MT/SS	—	762.67 a
MT/RC	724.47	548.36 bc
MT/TR	—	481.08 c
ZT/NC	859.02	689.78 a
ZT/TR	—	656.74 ab

† CT/NC = Conventional Tillage/No Cover; MT/NC = Minimum Tillage/No Cover; MT/SS = Minimum Tillage/Sub-soiling; MT/RC = Minimum Tillage/ Rye Cover; MT/TR = Minimum Tillage/Tillage Radish; ZT/NC = Zone Tillage/No Cover; ZT/TR = Zone Tillage/Tillage Radish

§ Numbers not followed by a letter are not different at the $P \leq 0.05$ level.

‡ Numbers followed by the same letter are not different at the $P \leq 0.05$ level.

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

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

† CT/NC = Conventional Tillage/No Cover; MT/NC = Minimum Tillage/No Cover; MT/RC = Minimum Tillage/ Rye Cover; ZT/NC = Zone Tillage/No Cover

§ IAE = Irrigation Application Efficiency

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

Table 5. Year two results for irrigation application efficiency, furrow advance time, infiltration volume, and runoff volume for a study conducted on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, MS 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/SS	64.1	121 bcd	53,119	29,791
MT/RC	59.4	154 ab	49,282	33,628
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/NC = Conventional Tillage/No Cover; MT/NC = Minimum Tillage/No Cover; MT/SS = Minimum Tillage/Sub-soiling; MT/RC = Minimum Tillage/ Rye Cover; MT/TR = Minimum Tillage/Tillage Radish; ZT/NC = Zone Tillage/No Cover; ZT/TR = Zone Tillage/Tillage

§ IAE = Irrigation Application Efficiency

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

Table 6. Offsite transport of total solids, filtered solids, and suspended solids through furrow irrigation water for a study conducted in 2015 and 2016 on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, MS.

	Year One			Year Two		
Treatment	Total Solids	Filtered Solids	Suspended Solids	Total Solids	Filtered Solids	Suspended Solids
	--------------------	kg ha^{-1}	--------------------	--------------------	kg ha^{-1}	--------------------
CT/NC†	109.84 a‡	52.21 b	57.24 a	46.5 c	38.4 bc	8.4 b
MT/NC	152.71 a	93.27 a	59.44 a	102.8 ab	78.7 a	24.1 b
MT/SS	—	—	—	62.7 bc	36.9 c	25.8 b
MT/RC	38.19 b	30.53 bc	30.53 b	47.7 c	43.9 bc	3.7 b
MT/TR	—	—	—	114.9 a	61.6 ab	53.4 a
ZT/NC	27.85 b	21.24 c	21.24 b	48.1 c	40.5 bc	7.6 b
ZT/TR	—	—	—	57.4 c	51.1 bc	6.4 b

† CT/NC = Conventional Tillage/No Cover; MT/NC = Minimum Tillage/No Cover; MT/SS = Minimum Tillage/Sub-soiling; MT/RC = Minimum Tillage/ Rye Cover; MT/TR = Minimum Tillage/Tillage Radish; ZT/NC = Zone Tillage/No Cover; ZT/TR = Zone Tillage/Tillage Radish

‡ Numbers followed by the same letter are not different at the $P \leq 0.05$ level.

Table 7. Offsite transport of total nitrogen and nitrogen species through furrow irrigation water for a study conducted in 2015 and 2016 on Bosket very fine sandy loam and Dubbs silt loam soils at Stoneville, MS.

	Year One				Year Two			
Treatment	TKN§	NH_4^+-N	NO_2^--N	NO_3^--N	TKN	NH_4^+	NO_2^-	NO_3^--N
	-------------------- kg ha^{-1} --------------------				-------------------- kg ha^{-1} --------------------			
CT/NC†	0.3441 ab‡	0.0136	0.0010 b	0.007 b	0.24 b	0.03	0.0012 d	0.0067 c
MT/NC	0.4503 a	0.0282	0.0045 a	0.045 a	0.69 a	0.164	0.0069 ab	0.039 abc
MT/SS	—	—	—	—	0.26 b	0.041	0.0033 cd	0.0052 c
MT/RC	0.2123 bc	0.0316	0.0029 ab	0.017 b	0.33 b	0.051	0.0018 d	0.0142 c
MT/TR	—	—	—	—	0.41 b	0.067	0.0029 cd	0.0228 bc
ZT/NC	0.1465 c	0.0119	0.0017 b	0.015 b	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/NC = Conventional Tillage/No Cover; MT/NC = Minimum Tillage/No Cover; MT/SS = Minimum Tillage/Sub-soiling; MT/RC = Minimum Tillage/ Rye Cover; MT/TR = Minimum Tillage/Tillage Radish; ZT/NC = Zone Tillage/No Cover; ZT/TR = Zone Tillage/Tillage Radish
§ TKN = Total Kjeldahl N
‡ Numbers followed by the same letter are not different at the $P \leq 0.05$ level.

Table 8. Offsite transport of total phosphorous and ortho-phosphate through furrow irrigation water for a study conducted in 2015 and 2016 on a Bosket very fine sandy loam and Dubbs silt loam at Stoneville, MS.

	Year One		Year Two	
Treatment	Total P	Ortho-Phosphate	Total P	Ortho-Phosphate
	-------------------- kg ha^{-1} --------------------			
CT/NC†	0.0345 b‡	0.0263 bc	0.019 c	0.026 c
MT/NC	0.0728 a	0.0564 a	0.063 ab	0.087 a
MT/SS	—	—	0.019 c	0.027 c
MT/RC	0.0384	0.0357 b	0.045 bc	0.068 ab
MT/TR	—	—	0.037 bc	0.051 bc
ZT/NC	0.0245 b	0.0220	0.077 a	0.079 ab
ZT/TR	—	—	0.049 b	0.056 abc

† CT/NC = Conventional Tillage/No Cover; MT/NC = Minimum Tillage/No Cover; MT/SS = Minimum Tillage/Sub-soiling; MT/RC = Minimum Tillage/ Rye Cover; MT/TR = Minimum Tillage/Tillage Radish; ZT/NC = Zone Tillage/No Cover; ZT/TR = Zone Tillage/Tillage Radish
‡ Numbers followed by the same letter are not different at the $P \leq 0.05$ level.