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# Cropping system and landscape characteristics influence long-term grain crop profitability

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**Abstract**

Converting from standard tillage or no-tillage cropping systems to more conservation-based cropping systems that include no-tillage, cover crops, and reduced agrichemical inputs must be profitable for large-scale adoption. Therefore, research was conducted at the central Mississippi River Basin site of the USDA Long-Term Agroecosystem Research Network from 1996 to 2009 to determine how cropping systems, landscape position, and depth to claypan affected net economic return. Treatments consisted of three cropping systems {mulch-till corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.], MTCS; no-till corn–soybean, NTCS; no-till corn–soybean–wheat (*Triticum aestivum* L.) (NTCSW)–cover crop} and three landscape positions (summit, backslope, and footslope). Within each cropping system, landscape position influenced the depth to claypan and net returns, which were greatest in the summit and footslope positions. Across landscape positions, net return for NTCS was US$252 and $119 ha$^{-1}$ yr$^{-1}$ greater than MTCS and NTCSW, respectively. Net return of corn in MTCS and NTCSW was negative, whereas corn in NTCS averaged $97 ha$^{-1}$ yr$^{-1}$. Only NTCS corn exhibited a positive linear response in net return to depth to claypan. Soybean was much more profitable than corn, and both NTCS and NTCSW soybean were less influenced by landscape position and had at least $252 ha$^{-1}$ yr$^{-1}$ greater return than did MTCS soybean across landscape position. Results suggest that converting from MTCS to NTCS would have large positive impacts on reducing within-field variability and increasing profitability in the region, and modifications to the NTCSW system are needed to improve profitability.

## 1 | INTRODUCTION

Claypan soils of the Major Land Resource Area (MLRA) 113 in the central U.S. Midwest pose many unique management challenges for corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] growers. Poor drainage, a

**Abbreviations:** CS, cropping systems; DTC, depth to claypan; LP, landscape positions; MTCS, mulch tillage corn–soybean system; NTCS, no-till corn–soybean system; NTCSW, no-till corn–soybean–wheat-cover system.

shallow restrictive layer, and a high propensity for N loss and erosion are some factors that commonly suppress productivity (Jamison, Smith, & Thornton, 1968; Kitchen, Sudduth, & Drummond, 1999). The shallow restrictive layer is an argillic horizon containing >500 g $kg^{-1}$ $soil^{-1}$ clay content and is commonly referred to as the "claypan" (Kitchen et al., 1999). This horizon is generally very acidic (pH = 4.0–4.5) and contains a high concentration of cations (Bray, 1935; Myers, Kitchen, Sudduth, Sharp, & Miles, 2007). Slow permeability caused by the claypan can lead to ponding and saturated field conditions during the optimum time period for spring planting of annual grain crops (Wiebold, 2010). Oftentimes, growers perform tillage to manage residue and warm up and dry out soil to allow for timely planting. Although seemingly practical, the soil loss associated with this annual or biannual tillage may subsequently decrease long-term agroeconomic sustainability. An alternative management practice is to convert these areas to perennial grasses or adopt no-tillage with cover crops. Both of these practices will impact water cycling.

In this MLRA nearly one-half of the original topsoil has been lost since European settlement in the 1800s (Bird & Miller, 1960). Consequently, as tillage continues and topsoil levels decrease, the clayey subsoil becomes closer to the surface or even exposed and the environment that supports root growth degrades (Myers et al., 2007). Topsoil depth, or the depth to the claypan (DTC), can vary from near 0 to more than 100 cm within fields (Kitchen et al., 1999). Typically, DTC is moderate (35 cm) on summits, shallower on backslopes (<10 cm), and deeper at footslopes (>50 cm; Myers et al., 2007). Studies ranging in size from small plots to field scale have consistently found yield to be most limited on areas with the greatest amount of erosion or shallowest DTC (Kitchen et al., 1999; Thompson, Gantzer, & Anderson, 1991; Yost et al., 2016). Further, this negative yield response can be exacerbated when large deviations above or below the average growing season precipitation occur (Conway et al., 2017; Yost et al., 2016;). Thus, attaining short-term goals with tillage may be degrading the long-term profitability of row-cropping these claypan soils.

Equivalent or enhanced long-term profitability must be attainable for a large percentage of agricultural producers to deviate from conventional tillage practices and adopt more conservation-based systems. However, contrasting results have been found when comparing the profitability of cropping systems (CS) across varying soil series. Research from the Mississippi Delta in eastern Arkansas on clayey soil found that conventional tillage produced US$30 $ha^{-1}$ $yr^{-1}$ greater net return than no-tillage across 7 yr in a soybean–sorghum [*Sorghum bicolor* (L.) Moench] CS (Parsch, Keisling, Sauer, Oliver, & Crabtree, 2001).

**Core Ideas**

- No-tillage increased net return for both corn and soybean production.
- No-tillage and cover crops did not improve net return over no-tillage alone.
- Extended crop rotation and the addition of cover crops maintained soybean net return.

Similarly, a study performed from 1994 to 2001 in North Dakota and Minnesota found that conventional tillage produced greater soybean and spring wheat (*Triticum aestivum* L.) yields and net returns when compared to no-tillage (DeVuyst, Foissey, & Kegode, 2006). Likewise, long-term (16 yr) research conducted in Indiana found that hypothetical, or modeled, net return was $25 $ha^{-1}$ greater with spring tillage than no-tillage on dark-colored, high organic matter, level, and poorly drained soil (Doster, Griffith, Mannering, & Parsons, 1983). Conversely, the study also concluded that no-tillage and spring tillage produced a similar net return on lighter colored, low organic matter, highly erodible, sloping, and well-drained soil. Because claypan soils are generally both poorly drained and highly erodible, applying these results to soils in the central claypan area would be difficult.

Spatial variability caused by varying DTC and landscape position (LP) within fields also affects grain crop productivity and profitability (Massey, Myers, Kitchen, & Sudduth, 2008). Previous research on plots with artificially created DTC has shown, in both tilled and no-tilled CS, that corn and soybean yield increased with DTC (Conway et al., 2017; Thompson et al., 1991). Likewise, net economic return to corn production across a 7-yr period exhibited a positive relationship with DTC across a range of environmental conditions (Conway et al., 2017). A larger field-scale study was also conducted in the region from 1993 to 2003 to evaluate net profitability of a mulch-tilled annual grain CS (Massey et al., 2008). The results showed the most eroded areas of the 36-ha research field produced the lowest net profitability across the 10-yr period. Similar to the small-plot study, low-lying areas with deep topsoil produced the greatest net profitability. However, the greatest temporal variability was also observed in these areas due to inconsistencies in plant stand densities. Therefore, additional and longer-term investigations are needed to understand how economic returns in more conservation-based CS, especially more dynamic systems with no-till, cover crops, and extended rotations, would be affected by variations in landscape and DTC.

Research from outside the claypan region has found LP to influence yield of a variety of grain crops. These differences have typically been attributed to temporal variability in plant available water (PAW) (Fiez, Miller, & Pan, 1994; Jones, Mielke, Bartles, & Miller, 1989). Further, a study conducted from 1994 to 2010 on the same plot area used in the present study found corn and soybean yield in a tilled CS decreased on backslopes with shallower DTC when compared to summit and footslopes with deeper DTC (Yost et al., 2016). The response was attributed to a decrease in saturated hydraulic conductivity on backslopes when compared to other LP (Jiang, Kitchen, Anderson, Sadler, & Sudduth, 2007). However, dissimilar results were found for the two no-till CS, where yield was not influenced by LP at the same site. Further research is needed to determine whether the increase in yield stability across LP with a no-till CS would improve overall profitability compared to a tilled CS.

In order for growers and consultants to shift management decisions towards longer-term objectives, an understanding of how different CS are influenced by spatial variability of the soil resource is vital. Although other research has provided insight regarding CS influence on net return in other states, and on other soil types, these questions have not been answered on claypan soils. Additionally, long-term economic evaluations of more comprehensive conservation systems with no-till, cover crops, and extended crop rotations are nonexistent or sparse on claypan and other soils. The objective of this long-term research was to determine how the interaction of two levels of conservation grain cropping (no-till corn–soybean [NTCS] and no-till corn–soybean–wheat [NTCSW]) and soil and landscape characteristics (LP and DTC) influence net return. Additionally, this study aimed to quantify how each centimeter of topsoil influences net return among CS and LP.

## 2 | MATERIALS AND METHODS

### 2.1 | Site description and experimental design

Research was conducted near Centralia, MO (39°13′48″ N, 92° 7′14″ W) on a site recently included in the USDA-ARS Long-Term Agroecosystem Research network (Kleinman et al., 2018; Sadler et al., 2015). The 12-ha study site was initially established in 1991 as part of the Missouri Management Systems Evaluation Areas project (Ward et al., 1994). Before establishment, the area had been continuously tilled and planted to mostly corn and soybean for more than five decades. The site was within MLRA 113 (3 mil ha) and was located on a typical claypan soil toposequence where summit (0–1% slope), backslope (1–3% slope), and footslope LP (<1%) were present. Landscape position designations were established from a survey performed by Missouri Cooperative Soil Survey personnel in conjunction with topographical maps. Mexico silty clay loam (fine, smectitic, mesic Vertic Albaqualfs) soil was most prominent on back and footslopes, while soils on summits were primarily Adco silt loam (fine, smectitic, mesic Vertic Albaqualfs). Both of these soil series are typical of claypan landscapes and contain an abrupt increase in clay concentration (argillic horizon; >500 g $kg^{-1}$ $soil^{-1}$ clay concentration) at a shallow depth within the soil profile (15–30 cm). Additional data, including soil physical and chemical characteristics as well as elevation, have been reported (Conway, Yost, Kitchen, Sudduth, & Veum, 2018; Jung, Kitchen, Anderson, & Sadler, 2007; Kitchen, Hughes, Donald, & Alberts, 1998; Myers et al., 2007; Veum et al., 2015; Yost et al., 2016).

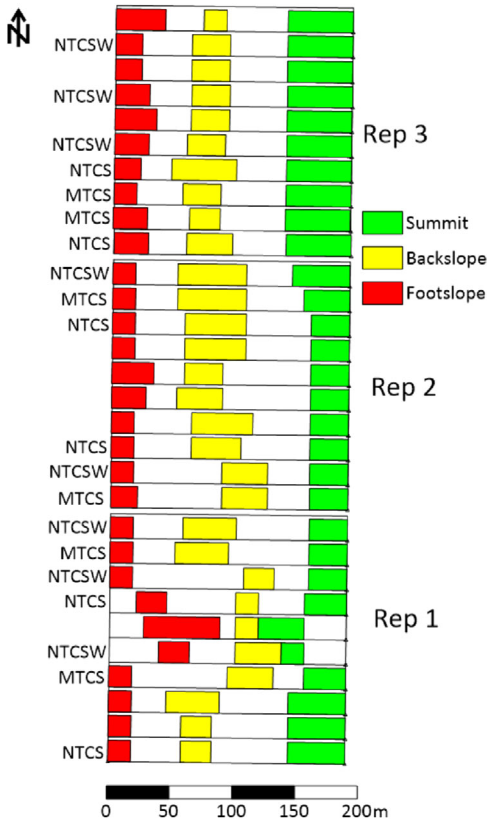


**FIGURE 1** Plot layout with cropping systems (MTCS, mulch tillage corn–soybean system; NTCS, no-till corn-soybean system; NTCSW, no-till corn–soybean–wheat–cover crop system) used in the analysis at the research site near Centralia, MO

The experimental design of the plot area was a randomized complete block design with a split-plot treatment arrangement. The main plots were six CS that were randomized and replicated three times (Figure 1). Each main plot was 189 m long by 18 m wide with the long side positioned parallel to the soil slope direction. Each plot contained three LP (summit, backslope, and footslope) split-plots that were not randomized. The split-plots varied slightly but were ≥18 m by 18 m in size. From this point forward all "split-plots" will be referred to as "plots". This study analyzed three of the annual grain CS that had not undergone major changes in management protocol for >20 yr. These CS included mulch tillage corn–soybean system(MTCS), no-till corn–soybean system (NTCS), and no-till corn–soybean–wheat–cover crop system (NTCSW). Each rotational phase of all CS were represented and replicated three times each year.

In the fall of 2010, DTC for each plot area was estimated using soil apparent electrical conductivity ($EC_a$). Soil $EC_a$ data were collected in parallel transects spaced 5 m apart across the length of each main plot with a DUALEM-2S electromagnetic induction sensor (DUALEM Inc.). Three 1.2-m deep by 4-cm diam. soil cores were also collected from near the center of each plot at the time of sensing ($n = 108$). Depth-to-claypan measured from these soil cores were used in combination with soil $EC_a$ data to model DTC for the entire plot area (Sudduth, Myers, & Drummond, 2013). The model validation root mean square error was 6.8 cm for the plots used in this study. The mean of the modeled DTC from all transects within the plot boundary were used as the plot-specific DTC. Depth to claypan averaged 16 cm on summits, 9 cm on backslopes, and 34 cm on footslopes. The standard error of DTC at each LP was approximately 2 cm. A map of the plot area DTC can be found in Jung, Kitchen, Sudduth, Lee, and Chung (2010).

## 2.2 | Plot management

### 2.2.1 | Tillage

One or two primary tillage passes with a disc-cultivator or disc-chisel (13- to 20-cm depth) occurred in MTCS in the early spring. These were followed by another pass with the same or similar tillage implements later in the spring to incorporate fertilizer and herbicide. A shallow (7–13 cm) secondary tillage pass or passes with a disc-cultivator, field cultivator, culti-packer, or spring tooth harrow were performed to prepare the seedbed. All tillage passes in MTCS targeted leaving about 30% of the previous crop residues on the soil surface after planting. Tillage was also performed in NTCSW from 1991 to 1995. The only tillage performed in NTCS and NTCSW after 1995 occurred in 2000 to incorporate fertilizer and in 2004 to terminate a failed soybean crop. In both 2000 and 2004, a rotary tine harrow (2.5-cm depth) was used.

### 2.2.2 | Fertility

Corn in all CS annually received between 113 and 267 kg N ha$^{-1}$ as solution urea ammonium nitrate (320 g N kg$^{-1}$) or ammonium nitrate (340 g N kg$^{-1}$). Nitrogen fertilizer was typically incorporated prior to planting in MTCS except for the last 2 yr of the study. Fertilizer N was surface- and split-applied in NTCS and NTCSW. Wheat in NTCSW received one-third (~34 kg N ha$^{-1}$) in the fall followed by an additional two-thirds (79 kg N ha$^{-1}$) applied between February and March as broadcast ammonium nitrate or urea-ammonium nitrate. Generally, no fertilizer N was applied to cover crops. However, low amounts (22–34 kg N ha$^{-1}$) were applied to annual ryegrass (*Lolium multiflorum* Lam.) and cereal rye cover crops in 2002, 2003, and 2006. Additional information regarding specific N rates for each CS can be found in Yost et al. (2016).

In 1992 a subset of plots within the 10.2-ha site were sampled for routine fertility analyses to the 15-cm depth. Results showed soil salt pH averaged 6.1, soil test phosphorus (STP) averaged 31 kg P ha$^{-1}$, and soil test potassium (STK) averaged 264 kg K ha$^{-1}$ (Buchholz, Brown, Garret, Hanson, & Wheaton, 2004). Lime was applied to all plots in 1992 and 2000. University of Missouri maintenance rates of fertilizer P and K were typically applied each year (Buchholz et al., 2004). Sometimes, however, build-up applications were made every 2nd or every 3rd year. This occurred in 1992, 2004, and 2006 where all plots were fertilized with build-up rates based on the University of Missouri recommendations to raise soil test levels. Across year and CS, annual fertilizer P rates averaged ~17 kg P ha$^{-1}$ and fertilizer K rates averaged ~27 kg K ha$^{-1}$. Gypsum was applied in NTCSW prior to wheat planting in 1999, 2000, and 2002. Rates varied between 10 and 15 kg S ha$^{-1}$.

### 2.2.3 | Seeding

Corn and soybean seeding operations varied some between years but were generally similar between CS each year. Corn was seeded in 0.76-m rows at rates from 50,900 to 71,200 seed ha$^{-1}$. Soybean was seeded in either 0.19- or 0.76-m rows at rates from 379,000 to 458,000 seed ha$^{-1}$. All corn and soybean seed was tolerant to glyphosate [*N*-(phosphonomethyl)glycine] and/or glufosinate [(*RS*)-2-amino-4-(hydroxy(methyl)phosphonoyl)butanoic acid] after 2000. Soft red winter wheat in NTCSW was sown in 0.19-m rows after soybean harvest in October each year. Seeding rates ranged from 90 to 134 kg seed ha$^{-1}$.

Cover crops for NTCSW were planted after corn harvest in 5 yr of the study (2002–2003, 2005, 2006–2007). These

**TABLE 1** Mean input costs across years by cropping system and crop, and crop values used in the economic analysis

| Cropping system | Crop | Input costs | | | | | | | Crop value |
|---|---|---|---|---|---|---|---|---|---|
| | | Total | Seed | Cover crops | Fertilizer | Pesticides | Harvest | Tillage | |
| | | US$ ha$^{-1}$ | | | | | | | \$ Mg$^{-1}$ |
| MTCS | Corn | 1,079 | 289 | 0 | 447 | 146 | 84 | 114 | 178 |
| | Soybean | 771 | 249 | 0 | 193 | 121 | 84 | 124 | 398 |
| NTCS | Corn | 968 | 282 | 0 | 435 | 165 | 84 | 5 | 178 |
| | Soybean | 556 | 217 | 0 | 126 | 126 | 84 | 5 | 398 |
| NTCSW | Corn | 1,008 | 269 | 49 | 422 | 173 | 84 | 2 | 178 |
| | Soybean | 605 | 222 | 49 | 126 | 116 | 84 | 5 | 398 |
| | Wheat | 571 | 126 | 49 | 314 | 7 | 74 | 0 | 219 |

*Note*. MTCS, mulch tillage corn–soybean system; NTCS, no-till corn–soybean system; NTCSW, no-till corn–soybean–wheat–cover system.

mixes consisted of cereal rye (*Secale cereale* L.) or annual ryegrass. Cereal rye and annual ryegrass were generally seeded at 33 kg ha$^{-1}$. Red clover (*Trifolium pratense* L.) was used as the primary cover crop after wheat harvest and was seeded at around 9 kg ha$^{-1}$. If red clover failed to establish, additional cover crop mixes such as soybean, cereal rye, or oat (*Avena sativa* L.) were planted.

### 2.2.4 | Pest control

Herbicide applications were made prior to planting and incorporated in MTCS. The no-till systems included a burndown and/or a post-emergence application. In general, 2.2 kg a.i. ha$^{-1}$ of atrazine [6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] were used in MTCS and NTCS. Atrazine rates were reduced to 1.1 kg a.i. ha$^{-1}$ in NTCSW. After 1998 corn in all CS received a post-emerge application of glyphosate or glufosinate. Soybean in all CS received similar post-emerge applications in all years after 2000.

### 2.2.5 | Yield

Corn and soybean were harvested between September and October after physiological maturity had been reached. Wheat was harvested in late June or July. A Gleaner R-42 combine (AGCO Corporation) was used to harvest all crops throughout the study. From 1991 to 1998, a weigh-bin system was used to collect yield data from the center 2.3 m of each plot. From 1998 to 2009, mean yield from the center 9.1 m of each plot was extracted from data collected with a yield monitor (Ag Leader Technology). The error associated with yield monitor data collection was estimated to be ≤5%. All grain moisture concentrations were corrected to 155, 130, and 135 g kg$^{-1}$ for corn, soybean, and wheat, respectively.

### 2.2.6 | Net Return

Net return (\$ ha$^{-1}$ yr$^{-1}$) was calculated by plot each year as the gross return (yield × market value) minus the sum of input costs (excluding land; Table 1), and was computed following agricultural economic guidelines (American Agricultural Economics Association, 2000). Annual input and output prices during 2007—2014 were considered in this analysis because of date, data availability, and relevance with current markets. This range included several years of higher-than-average input and output prices, which should be considered when interpreting the results of the study. Input costs consisted of purchased inputs (e.g., seed and agrichemicals) and machinery and labor estimated from custom farming rates. Each input price was either the average of the cost between 2007 and 2014 or the average price during 2013 and 2014 if there was a linear response in price over time according to linear regression results at $P \leq .10$ using the REG procedure of SAS (SAS Institute, 2011). This method does not account for intra- or inter-seasonal pricing and was chosen to highlight agronomic differences among cropping systems rather than input or output cost variability.

Most agrichemical prices were obtained from the North Dakota herbicide compendiums (Zollinger, 2014) or from prices reported from grower surveys (USDA-NASS, 2017; Table 1). When prices were unattainable from either of the previous sources, prices from local suppliers or actual prices paid for inputs were used. Custom farming rates reported from Iowa producer surveys were used for tillage, seeding, chemical, harvest, and soil sampling operations (Edwards & Johanns, 2014). Grain and cover crop seed prices were obtained from the USDA National Agricultural Statistics Service (USDA-NASS, 2017). Cover crop prices that were not reported by USDA-NASS were obtained from Green Cover Seed in Lincoln, NE. Additionally, when grain crop re-planting was required, one-half of the additional seed cost was charged. The price of cover crop establishment and lime, P, and K fertilizer applications were amortized across all years of the study. Annual market prices for corn, soybean, and wheat grain from nine Midwest states were obtained from the Center for Farm Financial Management (2017). A mean of market prices for each crop across 2007 to 2014 was used for calculating gross income.

#### 2.2.7 | Weather

Daily temperature and precipitation measurements were collected from a weather station located at the research site (Sadler et al., 2015). The 30-yr (1981–2010) average daily temperature and precipitation for the region were obtained from the National Oceanic and Atmospheric Administration National Centers for Environmental Information (https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/climate-normals/1981-2010-normals-data). Growing season (April–September) precipitation was >10% above the 30-yr average in 3 yr (1998, 2003, and 2008), >10% below in 5 yr (1997, 1999, 2002, 2005, and 2007), and was within 10% in remaining years of the study. The largest deviations in growing degree days (base 10 °C) occurred in 2005 (7% above) and 1997, 2008, and 2009 (7, 9, and 11% below average, respectively).

### 2.3 | Data analysis

The first 5 yr of data (1991–1995) were not used in the analyses because these years were considered transitional for initiating the CS effects. Data from 1996 to 2009 were analyzed at $\alpha = .10$ using the MIXED procedure in SAS version 9.2 (SAS Institute, 2011). This confidence level was chosen because of the inability to control spatial variability within the large experimental units. Annual net returns across years were the dependent variables used in all analyses. Cropping system, LP, and their interaction were considered fixed effects while block, year, and their interactions with fixed effects were considered random effects. Landscape position was repeatedly sampled over time and space during the duration of the study. Therefore, to assess for the likely correlation of the measures, the landscape position is treated as a repeated measure within the MIXED model approach. Landscape position was also considered a replicated treatment due to the fact that each main plot was managed independently. The Residual Maximum Likelihood method was used for parameter estimation. The first-order autoregressive covariance structure was used because it had the lowest Akaike's Information Criteria (AIC), AIC corrected, and Bayesian Information Criteria scores when compared to other covariance structures (e.g., compound symmetry, unstructured, toeplitz, etc.) evaluated. The UNIVARIATE procedure in SAS was used to assess equality of variance and normality. Additionally, model residuals were inspected and found to be normally distributed and homogenous. Fisher's protected LSD was used for mean separations at $\alpha \leq .10$.

Several linear and quadratic regression models were developed using the REG procedure in SAS (SAS Institute, 2011) at $P \leq .10$. The independent variables were DTC in linear regressions or DTC and DTC$^2$ in quadratic regressions. The dependent variables were mean net return across years, by crop, and within CS. Each LP in each plot had a unique DTC, and the same crop was not grown in a given plot for consecutive years due to the crop rotation. This resulted in 18 DTC observations for MTCS and NTCS. Although NTCSW had a total of 27 observations due to the extended rotation, only 18 were used in the analysis. These 18 were chosen because they had the greatest number of corn and soybean observations.

## 3 | RESULTS AND DISCUSSION

Commodity and input prices from 2007 to 2014 were used in this analysis. If a different, recent time period were chosen for prices, the relative results would be similar but the magnitude of the differences between CS and LP would be different. All conclusions would remain.

### 3.1 | Landscape position and cropping systems influence on net return

#### 3.1.1 | All crops

The interaction of LP and CS did not influence the net return across all crops (Table 2). However, the main effects of LP or CS did influence net return. Across CS, summit and footslope net return was similar and averaged \$147 ha$^{-1}$ yr$^{-1}$ (Figure 2a). Not surprisingly, backslope net return was \$101 ha$^{-1}$ yr$^{-1}$ less than summit or footslope positions. This response was caused by inferior yield on the backslope (Yost et al., 2016) mostly attributed to lower PAW. Topsoil loss has generally been the greatest at backslopes, resulting in greater clay content at the soil surface when compared to other LP (Bird & Miller, 1960; Jiang et al., 2007; Yost et al., 2016). Previous research conducted on the study site found greater slope and shallower DTC (mean = 9 cm) resulted in decreased saturated hydraulic conductivity on backslopes when compared to summit and footslope positions (Jiang et al., 2007). These results suggest that regardless of current

**TABLE 2** Significance of *F* tests for the influence of cropping system (CS), landscape position (LP), and their interactions on the net return of corn, soybean, wheat, and across all crops from 1996 to 2009

| Crop | Effect | df | *F* value | *P* > *F* |
|---|---|---|---|---|
| Corn | CS | 2 | 8.96 | .001 |
| | LP | 2 | 1.18 | .320 |
| | CS×LP | 4 | 3.47 | .009 |
| Soybean | CS | 2 | 31.41 | <.001 |
| | LP | 2 | 4.58 | .019 |
| | CS×LP | 4 | 2.68 | .032 |
| Wheat | LP | 2 | 2.34 | .118 |
| All crops | CS | 2 | 39.6 | <.001 |
| | LP | 2 | 2.46 | .100 |
| | CS×LP | 4 | 1.55 | .190 |

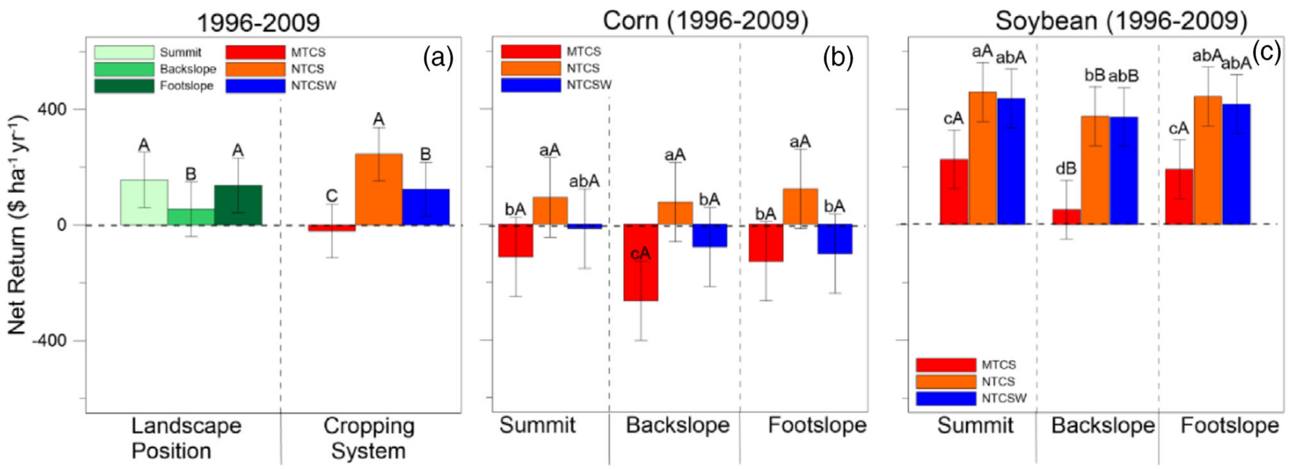


**FIGURE 2** Mean net return to (a) all crops, (b) corn, and (c) soybean as influenced by landscape position, crop, and cropping system (MTCS, mulch tillage corn–soybean system; NTCS, no-till corn–soybean system; NTCSW, no-till corn–soybean–wheat–cover crop system), and, where significant, their interactions. Within an independent variable, lowercase letters above bars represent differences within treatments (LP, CS, or crop) at $\alpha \leq 0.10$. Within an independent variable, uppercase letters above bars represent differences within and across different treatments at $\alpha < .1$. Error bars represent standard errors

CS, decades of erosion continue to influence profitability across the claypan soil landscape evaluated in this study.

The greatest average net return (\$245 ha$^{-1}$ yr$^{-1}$) across years and all crops among the three CS was observed in NTCS (Figure 2a). This was \$121 ha$^{-1}$ yr$^{-1}$ greater than NTCSW, and \$266 ha$^{-1}$ yr$^{-1}$ greater than the net return observed in MTCS. Inferior net return in NTCSW when compared to NTCS was caused, in part, to the lower frequency of the most profitable crop (soybean) due to the extended rotation with wheat (Table 1). Further, the additional expense of seeding cover crops (Table 1) and suppressed corn yields in NTCSW (Yost et al., 2016) also contributed to a reduction in net return. Negative net return in MTCS was caused by the additional cost of tillage, reduced corn yield, and additional fertilizer and chemical input when compared to the other two CS. The difference between MTCS and the other no-till CS could expand or decrease if major changes in input costs (e.g., fuel or herbicide) were to occur. These results are contradictory to other studies in the U.S. Midwest that have found greater or equivalent net return with tillage when compared to a no-tillage system (Doster et al., 1983; Parsch et al., 2001; DeVuyst et al., 2006). This departure likely is due to the vulnerability of claypan soils to topsoil loss that leads to degraded soil productivity with long-term tillage practices (Bird & Miller, 1960; Jung et al., 2007; Lerch et al., 2005). This soil-loss driven degradation was quantified in 2010, when soil quality indicators were measured on the same plot area to evaluate CS influence on soil properties after 19 yr (Veum et al., 2015). Results found that across a suite of measurements, total Soil Management and Assessment Framework (SMAF) scores in the upper 5 cm of the soil profile were greater in both no-tillage systems when compared to MTCS. The largest departure between systems occurred in the biological SMAF component, where organic C, β-glucosidase, microbial biomass, and mineralizable N were all greater in both no-till CS. Enhanced soil quality indicator levels in these systems likely increased water infiltration and soil N supply throughout the growing season.

Results from the present study suggest converting from tillage to no-till system may have large profitability benefits to growers in the region. Conversely, extended rotations and the inclusion of cover crops may only slightly increase net return when compared to MTCS. This is largely due to the marginal net returns to wheat observed across LP (mean = \$21 ha$^{-1}$ yr$^{-1}$). However, wheat yield has been found to be more temporally stable than corn or soybean on claypan soil (Yost et al., 2016). Thus, if the value of wheat were to increase or the cost of wheat production were to decrease, and given that NTCSW has shown additional improvements over NTCS in some soil quality indicators (Veum et al., 2015), NTCSW may become more profitable than both MTCS and NTCS over time (i.e., more sustainable).

### 3.1.2 | Corn

The net return to corn was influenced by the interaction of CS and LP (Table 2; Figure 1). In NTCS, the net return was positive across LP, while MTCS and NTCSW were negative. On the summit, the net return was \$208 ha$^{-1}$ yr$^{-1}$ greater in NTCS (\$94 ha$^{-1}$ yr$^{-1}$) than MTCS (\$−114 ha$^{-1}$ yr$^{-1}$). Net return on footslopes were similar between MTCS and NTCSW (mean = \$−116 ha$^{-1}$ yr$^{-1}$), and both were at least \$225 ha$^{-1}$ yr$^{-1}$ less than NTCS. The most negative net return of any CS was observed in MTCS on the backslope (\$−264 ha$^{-1}$ yr$^{-1}$). This was \$341 ha$^{-1}$ yr$^{-1}$ lower than NTCS and \$186 ha$^{-1}$ yr$^{-1}$ lower than NTCSW. These results illustrate the need to significantly alter management on backslopes in MTCS to improve profitability. The response observed in MTCS was attributed to inferior yield caused by decreased water infiltration under the long-term tillage CS (Jiang et al., 2007). Additionally, others have found tillage can increase soil temperature and oxygen levels, resulting in previously protected organic matter (OM) becoming available and consumed by soil microbial consortia (Balesdent, Barlett, & Doner, 1988; Weil & Brady, 2017). As expected, OM levels in both no-tillage systems (mean = 25 g kg$^{-1}$) were greater than in MTCS (22 g kg$^{-1}$; Conway et al., 2018). Lastly, the combination of tillage prior to seeding and greater clay content on backslopes (Jiang et al., 2007) often resulted in surface crusting, creating conditions for plant emergence stress and, consequently, lower corn plant populations. Stand counts were not measured consistently by landscape position, but field observations confirmed this happened often.

Long-term results illustrate that a MTCS on claypan soil was not profitable in many years (Dolginow, Massey, Kitchen, Myers, & Sudduth, 2014; Massey et al., 2008). Results do, however, illustrate large potential to increase profitability (\$208–341 ha$^{-1}$ yr$^{-1}$) with a NTCS, especially on fields with a high percentage of backslope positions where previous erosion has occurred. Additionally, converting to NTCS could increase long-term economic stability by decreasing soil loss and improving soil health (Lerch et al., 2005; Veum et al., 2015).

Surprisingly, the benefits of a no-till CS were diluted by the inclusion of cover crops and an extended crop rotation with wheat in NTCSW. As previously stated, the reduction in net return was attributed to the added expense of seeding cover crops, as well as poor corn establishment when seeding into heavy cover crop residue. These residues decreased planter performance and caused more cool and moist soil conditions (Teasdale & Mohler, 1993). Collectively, these factors likely slowed corn germination and allowed seedlings to be more susceptible to disease, predation, and more extreme moisture and temperature fluctuations (Salem, Valera, Munoz, Rodriguez, & Silva, 2015). Further, N availability may have been decreased due to N immobilization in cover crop residues (Mitchell & Tell, 1977; Rice & Smith, 1984).

### 3.1.3 | Soybean

Similar to corn, the interaction of CS and LP influenced the net return to soybean from 1996 to 2009 (Table 3). Unlike corn, mean soybean net return was positive across CS and LP (Figure 2c). Likewise, both no-tillage CS responded similarly across LP. The net return of these CS averaged \$450, \$383, and \$430 ha$^{-1}$ yr$^{-1}$ on summit, backslope, and footslope positions, respectively. Similar responses in NTCS and NTCSW were attributed to successful soybean stand establishment into cover crop residue. Later seeding dates for soybean, when compared to corn, resulted in generally warmer and drier soil conditions for soybean emergence. Additionally, residues from cover crop species such as cereal rye likely helped preserve moisture later in the growing season and inhibit weed seed germination (Cornelius & Bradley, 2017).

Soybean net return was much less (mean = \$154 ha$^{-1}$ yr$^{-1}$) across LP in MTCS than in the other two CS. This response was attributed to slightly decreased yield (Yost et al., 2016) and increased tillage and agrichemical input costs for MTCS. Although the lowest net return of all crops was observed in all CS on the

**TABLE 3** Linear or quadratic regression equations and parameters describing corn or soybean net return ($ ha$^{-1}$ yr$^{-1}$) response by cropping system (CS) to depth to claypan (DTC) at the study site near Centralia, MO. In the equations, $y$ = profit (US$ ha$^{-1}$) and $x$ = DTC (cm)

| Years | Crop | Equation | Model probability | $r^2$ [a] | $Y_{max}$ [b] |
|---|---|---|---|---|---|
| Corn | MTCS | $y = -165$ | .79 | na | na |
| | NTCS | $y = -59 + 6.85x$ | <.01 | .32 | 342 |
| | NTCSW | $y = -61$ | .43 | na | na |
| Soybean | MTCS | $y = -65 + 23.4x - 0.46x^2$ | <.01 | .40 | 233 |
| | NTCS | $y = 402$ | .30 | na | na |
| | NTCSW | $y = 375$ | .64 | na | na |
| Wheat | NTCSW | $y = 20$ | .16 | na | na |

*Note*. MTCS, mulch tillage corn–soybean system; NTCS, no-till corn–soybean system; NTCSW, no-till corn–soybean–wheat–cover system; na, not available.
[a] $r^2$ values are not shown for nonsignificant regression models.
[b] $Y_{max}$, greatest net return observed.

backslope, the soybean net return in MTCS decreased more dramatically (77%), when compared to summit and footslope positions. Conversely, soybean net return in the no-tillage CS only decreased 15%. These results demonstrate that no-tillage has the potential to reduce within-field net return variability caused by eroded backslopes. However, these results do not support the inclusion of cover crops and an extended rotation to bring additional profit or profit stability across this claypan landscape.

## 3.2 | Depth to claypan and cropping system influence on net return

Previous research on a claypan soil site located about 35 km from the present study used net return to estimate the value of each 1 cm of topsoil in a corn and soybean rotation (Conway et al., 2017). Results indicated that, on average, each 1 cm of topsoil resulted in a $14 ha$^{-1}$ yr$^{-1}$ increase in net return each year of corn production, but soybean net return was not influenced by DTC across a range of wetter and drier-than-average environmental conditions. Although their results are pertinent, the Conway et al. (2017) study was located on much smaller plots with artificially constructed DTC. Additionally, no slope was present nor was LP, with inherent "runoff and run-on" properties represented. Because topsoil depths were estimated for each LP within plots, the present study allowed for the evaluation of DTC influence on net return across a natural claypan soil landscape. Additionally, the DTC (continuous) analysis in the present study also allowed for the evaluation of the influence of DTC on net return.

### 3.2.1 | Corn

Net return in NTCS increased $6.85 ha$^{-1}$ yr$^{-1}$ with each 1 cm increase in DTC (Table 3; Figure 3a). This suggests that although NTCS was the most profitable, this CS was consistently susceptible to soil landscape variability. This linear response was not as intense as the quadratic-plateau response observed by Conway et al. (2017), who reported net return increased $14 ha$^{-1}$ yr$^{-1}$ as DTC increased from 0 to 31 cm. Interestingly, neither MTCS or NTCSW responded to DTC. This does not align with previous research that found corn yield increased with DTC (Conway et al., 2017; Thompson et al., 1991). The lack of response in the present study was attributed to the inclusion of slope and LP that, in some years, inhibited corn yield on footslopes with deeper DTC. Sheet erosion oftentimes buried and/or exposed seedlings when heavy rainfall events occurred after planting in MTCS. Conversely, greater compaction was observed on footslopes in NTCSW than in the MTCS (Jung et al., 2010). This occurred because heavy residues preserved moisture during times when much of the machinery traffic occurred. Furthermore, this was compounded by a greater number of passes with machinery (i.e., cover crop seeding, in-season N applications) when compared to other CS. Together, heavy residue and compaction likely resulted in cool and anaerobic conditions for corn seedlings, and probably led to denitrification as soil warmed up later in the growing season (Blevins, Wilkison, Kelly, & Silva, 1996; Salem et al., 2015). Collectively, these factors likely reduced the greater corn yield potential at deeper DTC in MTCS and NTCSW that has been observed in previous studies conducted in the region (Conway et al., 2017; Thompson et al., 1991).

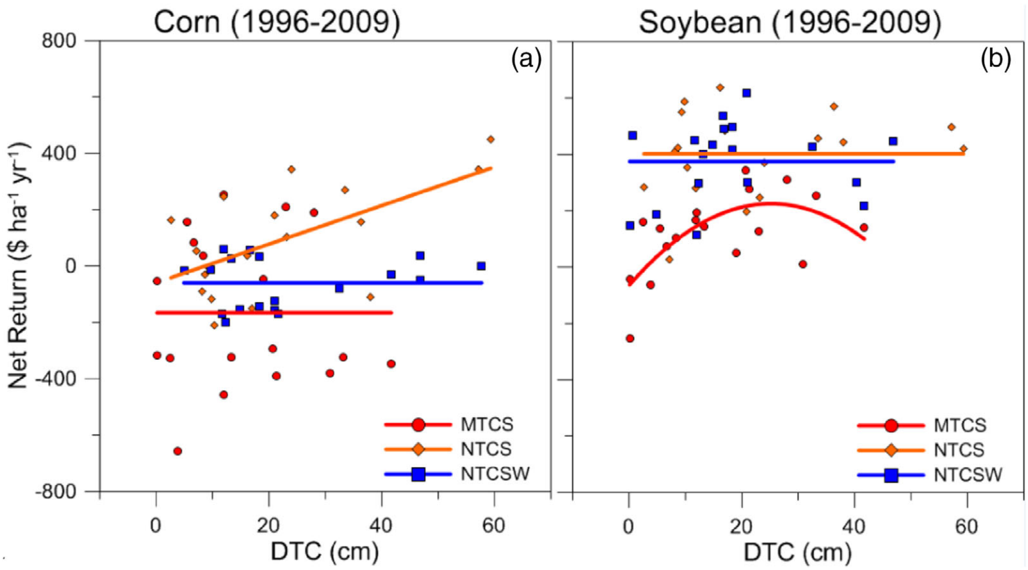


**FIGURE 3** Net return as affected by depth to claypan (DTC), by crop, and by cropping systems (MTCS, mulch tillage corn–soybean system; NTCS, no-till corn–soybean system; NTCSW, no-till corn–soybean–wheat–cover crop system). Lines represent best-fit models of regressions presented in Table 3

### 3.2.2 | Soybean

Net return in MTCS was influenced by DTC. As DTC increased from 0 to 25 cm, net return increased from $6 to a maximum of $256 ha$^{-1}$ yr$^{-1}$ (Table 3; Figure 3b). This suggests that, on average, each centimeter of topsoil (up to 25 cm) under soybean production in a MTCS is worth about $10 ha$^{-1}$ yr$^{-1}$. These results are supported by small plot research which found soybean yield in a MTCS to increase slightly (0.013 Mg ha$^{-1}$) with each 1 cm increase in DTC (Thompson et al., 1991). Unlike corn, NTCS soybean net return was not influenced by DTC. These results are supported by previous research that found soybean net return in no-tillage to be unaffected by DTC across a range of wet and dry years (Conway et al., 2017). This also aligns with a study that found less within-field yield variation in soybean production when compared to corn on claypan soil (Kitchen, Sudduth, Myers, Drummond, & Hong, 2005). These results add more evidence that converting to a no-tillage CS can increase revenue and further decrease variability caused by field areas with reduced DTC.

Similar to the other no-till system, soybean net return in NTCSW did not respond to DTC. As observed for corn, the lack of response may have been caused by suppressed yield potential at footslopes. However, when looking at shallower DTC, soybean net return increased from 234 to 527 ha yr$^{-1}$ as DTC increased from 0 to 30 cm ($P = .06$; $r^2 = .20$). Conversely, at deeper DTC net return averaged $321 ha$^{-1}$ yr$^{-1}$ at DTC > 30 cm. The extra residue present from cover crop species, such as cereal rye, at the time of soybean planting may also have inhibited soybean emergence and subsequently reduced yield potential in these areas.

## 4 | CONCLUSIONS

This research adds to existing research in the claypan region by demonstrating that transitioning to a conservation-based no-till system can result in significant improvements to long-term profitability. The NTCS consistently produced a greater net return than the MTCS in both corn and soybean production. In fact, NTCS was the only system of the three evaluated that had positive net returns to corn over years. Including wheat and cover crops in NTCSW provided no additional profit benefits above NTCS after 14 yr. However, NTCSW did economically outperform MTCS in many cases, especially on backslopes, suggesting NTCSW may be a viable alternative to conventional management. Furthermore, the NTCSW performed similar to NTCS under soybean production, suggesting that a modified NTCSW that excludes wheat and includes cover crops prior to soybean only may provide the benefits of cover crops without reductions in profit.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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