7-2021

Crop Yield and Economics of Cropping Systems Involving Different Rotations, Tillage, and Cover Crops

J. Singh

T. Wang
South Dakota State University, tong.wang@sdstate.edu

S. Kumar

Pete Sexton
South Dakota State University, Peter.Sexton@sdstate.edu

J. Davis

See next page for additional authors

Recommended Citation

J. Singh, T. Wang, S. Kumar, Z. Xu, P. Sexton, J. Davis and A. Bly Journal of Soil and Water Conservation July 2021, 76 (4) 340-348; DOI: https://doi.org/10.2489/jswc.2021.00117

Authors

J. Singh, T. Wang, S. Kumar, Pete Sexton, J. Davis, and A. Bly

Crop yield and economics of cropping systems involving different rotations, tillage, and cover crops

Abstract: Diversified cropping systems integrated with winter cover crops and no-till (NT) system can provide substantial soil conservation benefits in the Midwest Corn Belt of the United States, but there is uncertainty on how these practices affect producer profits. This study compared crop yield and economic performance from cropping systems that featured three crop rotations— corn (*Zea mays* L.)-soybean (*Glycine max* [L.] Merr.; 2-yr), corn-soybean-oat (*Avena sativa* L.; 3-yr), and corn-soybean-oat-winter wheat (*Triticum aestivum* [L.]; 4-yr); two tillage systems—NT and conventional-till (CT); and two cover cropping managements—cover crop (CC) and no-cover crop (NC). Tillage and rotation treatments were established in 1991, whereas cover cropping was introduced in 2013, so data from 2014 through 2018 was used for the yield and economic comparisons. Over the study period, the NT system reduced the corn yield across all rotations but increased the soybean yield under 2-yr rotation as compared to the CT system. Hence, both tillage systems were economically equivalent, whereby NT system improved benefit-cost ratio as compared to the CT system. In our study, while CC in its short-term did not contribute to yield and overall economic benefits, but we observed highest gross revenue and second best net returns from 2-yr-CC plots under the NT system as compared to all other cropping systems. When compared to 2-yr rotations, diverse crop rotations (3- and 4-yr) increased the corn and soybean yields and associated profits; yet compromised overall profitability due to the lower profits of small grains. Therefore, it is important to identify other profitable crops to diversify the corn-soybean rotations that are beneficial for soils and the environment.

Key words: cover crops—diversified rotations—no-till—benefit-cost ratio—crop yield—net returns

Conservation agriculture represents a set of three soil health principles: (1) direct planting of crops with minimum soil disturbance (e.g. no-till [NT]), (2) permanent soil cover by cover crops (CCs), and (3) crop rotation (Pittelkow et al. 2015; Singh 2020). These principles have broadly received attention for enhancing functional diversity of cropping systems and addressing food security challenges with reduced external inputs and minimal environmental impacts (Philip Robertson et al. 2014; Mosquera et al. 2019). Studies demonstrate that diverse crop rotations, CCs, and NT can mitigate erosion (Delgado and Gantzer 2015), improve soil health through increased organic matter (Maiga et al. 2019; Singh et al. 2020), maintain nutrients in the soil (Karlen et al. 2013), and reduce the amount of pollution entering water bodies (Blanco and Lal 2010; Himanshu et al. 2019) as well as in the atmosphere (Wegner et al. 2018).

For a crop management practice to be sustainable, it must also be profitable. Most studies only consider yields and do not convert yields to returns. Crop yields is one factor that contributes to profitability of any management alternative. Despite soil health benefits from conservation practices, there has been considerable research showing inconsistent findings on crop productivity under different soils and environmental conditions. For example, Hairston et al. (1984) reported that in silty clay soils, soybean (*Glycine max* [L.] Merr.) yields were lower under NT than fall-chisel tillage system. Others (e.g. Pittelkow et al. 2015; Hammel 1995; Dick et al. 1986; Daigh et al. 2018) also noted an either decline or no influence on crop yield followed by NT as compared with tilled systems. In contrast, individual crop yield under NT system could increase when crops are planted in rotations (Wilhelm and Wortmann 2004; Katsvairo and Cox

2000). The mixed impact of tillage on yields may be attributed to crop diversity. In South Dakota, Anderson (2016) reported that increasing cropping intensity two-fold, the corn (*Zea mays* L.) yield under NT increased by 116% compared with the conventional tillage (CT) system. However, the positive benefits of crop diversity are not universal with some studies reporting yield increases (e.g. Heck et al. 2013; Smith et al. 2008), no impact (Smith and Gross 2006; Delate and Cambardella 2004) or decrease (Porter et al. 2003) in crop yield due to complexity of crop rotation. The inconsistent response of crop yields to management factors such as tillage and rotation is understandable because individual crops interact differently with soil types, crop management practices (Krupinsky et al. 2006) and fluctuating weather conditions (Gaudin et al. 2015). Therefore, to develop efficient and profitable agroecosystems, there is a need to understand the interaction between location specific management practices with certain crop rotations and tillage combinations (Anderson 2005; Sakurai et al. 2011).

The length and complexity of cropping systems have decreased in the Midwest Corn Belt of the United States (O'Brien et al. 2019; Chatterjee et al. 2016). A possible reason for low crop biodiversity is probably due to the higher associated net returns with the corn-soybean rotation as compared to the other rotations (Meyer-Aurich et al. 2006; Roesch-McNally et al. 2018). Inclusion of small grain [e.g. wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and oat (*Avena sativa* L.)] and use of winter cover crops (CC) have been proposed as management alternatives to diversify cropping systems in soils located in temperate climates (Gaudin et al. 2013). In general, there is a short period available (fall through spring) after summer conventional rotations (corn and soybean) to insert these alternatives and this can be influenced by water-stress conditions. However, in recent years, it has become feasible to plant frost seeded crops such as winter wheat and rye (*Secale cereale* L.), during the winter-fallow period (Fowler

2012). These alternatives have the potential for improving individual crop yield (Götze et al. 2017) and enhancing cash crop (corn and soybean) productivity in NT system (Kabir and Koide 2002).

Concerns about economic feasibility appear to be a dominant factor that deters adoption of conservation cropping systems (Dunn et al. 2016). Various studies suggested that long-term use of conservation practices (e.g. NT, CC, and diversified crop rotations) could reduce production risk and increase profitability (e.g. Soule et al. 2000; Karlen et al. 2013; Mbuthia et al. 2015; Archer et al. 2018). However, producers often focus on short-term profitability and net return when selecting cropping systems on their farms (Meyer-Aurich et al. 2006). Therefore, it is of great importance to compare the economic and agronomic performances of cropping systems that include different combinations of tillage, crop rotation and CCs (Stanger et al. 2008b; Al-Kaisi et al. 2015).

Limited published information is available on crop yields and economic returns of cropping systems. Thus, the main objective of this study was to compare the economic performances of 12 cropping systems that featured three crop rotations [corn-soybean (2-yr), corn-soybean-oat (3-yr), and corn-soybean-oat-winter wheat (4-yr)], two tillage systems (NT vs CT) and two cover type managements [CC vs no-cover crop, (NC)]. This study would be helpful to farmers to identify the most profitable cropping systems based on market prices in recent years.

Materials and Methods

Experiment Description. The experiment was conducted at the South Dakota State University Southeast Research Farm near Beresford, SD (43°02’58” N, 96°53’30”W) from 2014 through 2018 on an Egan silty clay loam (fine-silty, mixed, superactive, mesic Udic Haplustolls) soil. The region has a humid continental climate with the 66-yr (1962-2018) average annual precipitation of approximately 650 mm (25.59 in) and average maximum and minimum temperature of 14.69°C (58.44°F) and 1.84°C (35.31°F) respectively. Experimental design was a randomized complete block design in a split-split plot treatment arrangement with four replications.

Rotations, tillage, and cover cropping were assigned as main-plot, sub-plot, and sub-sub-plot factors, respectively. The size of the sub-sub plots were 90 m (295 ft) wide by 10 m (33 ft) long. The three crop rotations [corn-soybean (2-yr), corn-soybean-oat (3-yr), and corn-soybean-oat-winter wheat (4-yr)] and two tillage systems [no-till (NT) and conventional-till (CT)] at the site were initially established in 1991, and cover cropping [cover crop (CC) and no-cover crop, (NC)] was initiated following the main crops harvest in the fall of 2013. To eliminate year bias, all phases of each rotation were included with a total of eighteen crop phases (six corn and soybean phases of each rotation, four oat phases, and two winter wheat phases) planted annually. Winter rye and a broadleaf blend [radish (*Raphanus sativus* L.), 2.35 kg ha^{-1}; dwarf essex (*Brassica napus*), 1.46 kg ha^{-1}; turnip (*Brassica rapa* L.), 0.34 kg ha^{-1}; peas (*Pisum sativum* L.), 4.93 kg ha^{-1}; lentil (*Lens culinaris*), 3.59 kg ha^{-1}; oat, 5.38 kg ha^{-1}; cowpea (*Vigna unguiculata* L.), 1.79 kg ha^{-1}; millet (*Panicum miliaceum*), 1.79 kg ha^{-1}; hairy vetch (*Vicia villosa* Roth.), 2.91 kg ha^{-1}] were used as two CC in this study. Winter rye was direct seeded between corn and soybean immediately after corn harvest in all rotations and were chemically terminated ahead of soybean planting. The termination timing of winter rye was inconsistent and generally depend on weather or moisture conditions, and time interval between termination and soybean planting varied from 2 to 22 days over the course of study. Broadleaf blend was seeded after oat and winter wheat harvest in the 3- and 4-yr rotation, respectively before the corn planting and winter killed by frost weather. The crops for 3- and 4-yr rotations have not been consistent over the course of the study since their establishment in 1991. The 3-yr rotation was initially started with corn-soybean-spring wheat until 2005, and then field pea was substituted for spring wheat and the rotation pattern became corn-field pea-soybean for 2006 to 2010 period. Similarly, the 4-yr rotation initially included corn-soybean-spring wheat-alfalfa until 2005, and then transitioned to corn-field pea-winter wheat-soybean sequence for 2006 to 2010 growing period. From 2011 onwards, the cropping sequences for both 3-yr and 4-yr rotations remain unchanged. An overview of the cropping sequence for different rotations with and without CC for this study period (2014 to 2018) is given in table 1.

All rotation and cover crop treatments were managed both with NT and CT systems. The NT plots had not been tilled since the trial began in 1991. The CT plots consisted of a combination of fall chisel plowing following the harvest of corn and small grain stubble, and spring field cultivation to a depth of 15 to 20 cm (5.91 to 7.87 in) as a seedbed preparation for planting crops. The fall chisel plowing was skipped before winter wheat establishment in the 4-yr rotation under CT system. During wet conditions in the fall, the chisel plowing of corn stubble was prevented, and the CT plots were disked in the spring and then field cultivated before planting.

The field operations used in the study are typical for eastern South Dakota, with slight deviation from year to year due to variable conditions in soil moisture, weed pressure, and weather. Fertilizers and herbicides for all available plots were applied at conventional rates to ensure that crop productivity was not adversely affected by soil fertility and weed competition, respectively. No adjustment in fertilizer rates were made in accordance to crop rotation and cover crops N credits during the management of various crops. Oats and winter wheat straw were baled and removed after grain harvest; however, they were not included in any economic calculations as no record was kept while baling the residues. Cover crops in the form of winter rye and blend were not harvested for forage. Field records kept for each treatment included the dates on which each field operation was performed, the quantity of operating inputs applied and crop yields. An overview of the inputs used for different crops during the 2014 to 2018 growing period is presented in table 2.

Economic Methodology. Although the study commenced in 1991, the CCs was not in place until 2013, so the economic analysis was conducted using the data from 2014 through 2018. Costs of production, gross revenues, net returns, and benefit-cost ratios (BCRs) of different management alternatives (tillage x rotation x cover cropping) were calculated and compared to identify the strengths and weakness of different cropping systems.

For all specified management alternatives, the annual budgets were assembled based on primary field data and secondary price data over the 5-yr study period. Primary field data collected annually at the research site included timing and number of field operations performed, quantity of material inputs like seeds, fertilizer, pesticides, and the replicated level of crop yield. Secondary data, including output prices, input prices, and custom rates for specified field operations, were collected to estimate specific management costs and returns. Average annual market year prices (2014-2018) received for South Dakota were used for crop prices (USDA-NASS 2018). Costs for seed, fertilizer and crop insurance were determined by multiplying the variable inputs within each production system for each plot in each year by the annual input prices obtained from local agribusinesses. Machinery costs for cultural practices such as planting, fertilizer and herbicide application, harvesting, drying and hauling were determined using 5-yr average custom rates for North Dakota (Haugen 2016). Gross revenues were computed based on average plot yields under different practices and annual commodity prices received. Net returns were calculated as the difference between gross returns and production costs. To simplify the analysis, no charges for management, land or overhead costs were included in the calculations as these costs are similar across different treatments and therefore have little effect on the outcome of the analysis.

Statistical Analysis. Crop yield, as well as cost, BCRs, gross revenues and associated net return were analyzed based on randomized complete block split-split plot design with repeated measures across time and block using the GLIMMIX procedure of SAS statistical software version 9.3 (Institute 2011). Pairwise comparisons for each variable were performed by first averaging inputs and outputs by plot for each of the 12 management practice combinations before conducting analysis of variance (ANOVA). Average separation among treatment means and interactions were obtained by using LSMEANS procedure in the SAS. In all statistical calculations, an effect was significant if $P < 0.05$.

Results and Discussion

Weather Conditions and Crop Yield. In general, soils and weather conditions during the period of the experiment were optimum for the crop growth. The growing season precipitation (Apr. to Sept.) at the site for 2014, 2015, 2016, 2017 and 2018 was about 25%, 31%, 24%, 20%, and 44% greater than the long-term 66-yr (1962 to 2018) normal of 488 mm (19.21 in), respectively (table 3). Annual crop yields for the four cash crops, measured as average yield values across different treatments, were displayed in table 3. Despite higher than normal precipitation levels during the study period, considerable yield variability (evaluated by calculating the coefficient of variation, CV) was observed for all four crops. The relative range of yields observed over the 5-yr period was most dramatic for winter wheat; whose highest annual mean yields (2016 and 2017) were more than twice its lowest mean yield in 2014. Average across the study years, the CV values for corn, soybean, oats, and winter wheat were 14%, 13%, 27%, and 28%, respectively. Large variation in small grain yields could be attributed to spring precipitation that interfered with planting (oats) and harvesting (oats and winter wheat), poor weed control, and herbicide drift injury.

Management Effects on Crop Yield. In this study, cropping system diversification was achieved through small grains (oat and winter wheat) and CC. Over the study period, diversified crop rotations (3- and 4-yr) enhanced yields of corn and soybean (table 4), which agrees with other studies (e.g. Davis et al. 2012; Liebman et al. 2008). Corn yield, on average, was 6% and 4% greater in the 4-yr than in the 2-yr and 3-yr rotations, respectively (table 4, P= 0.001), whereas, there was no difference between the 2-yr and 3-yr rotations. Soybean yield during the study period was on average 4% greater in the 4-yr than in the 2-yr rotation (4.02 vs 3.86 Mg ha^{-1}**)**, however, the effect was not statistically different (table 4, P= 0.054). Despite productivity gains for corn and soybean yields, oat yields did not differ between the 3- and 4-yr rotations (4.11 vs 3.98 Mg ha^{-1}, P= 0.122), which is in agreement with other literature findings (Stanger et al. 2008a; Liebman et al. 2008).

Small grains are widely promoted in the Midwest regions as rotational crops because they also give an opportunity to plant CCs after their harvest in late July and early August. Generally, multispecies CC mixtures are recommended due to their multifunctional benefits that include erosion control, weed suppression, N retention and SOM accumulation (Finney et al. 2017; Hunter et al. 2019). In this study, we included cool-season legumes, brassica, and millets under the blend-CC mixture in the 3- and 4-yr rotations for dual provisioning of N retention and supplementary N to the subsequent crop in addition to soil and water conservation benefits from their surface mulch. Our data suggests that corn yield following blend-CC was reduced by 3% compared to the NC plots (11.38 vs 11.67 Mg ha^{-1}, P= 0.048) over the study period. However, when data was analyzed separately for each year, we observed that effect of cover cropping was only statistically different for 2017 ($P<0.001$). This may be partially attributed to the fact that drainage tiles were installed in the study plots during the spring of 2017, and hence management practices suffered considerably during this year. Nevertheless, in other years, a slight decrease in corn yield can be attributed to blend-CC establishment issues such as weed pressure after small grains (Lee and McCann 2019), residual herbicide effects (Cornelius and Bradley 2017), and in part due to poor synchronization of cover crop N mineralization and corn N need and uptake (Wagger 1989; Sullivan et al. 1991). We further diversified crop rotations by planting winter rye-CC on corn stalks and then evaluated its influence on soybean yields. Averaged across all rotations, soybean yield following winter rye-CC was not significantly different from that in the NC plots. This is consistent with other Midwestern studies (e.g. De Bruin et al. 2005; Bauer 1991), those reported no reduction in soybean yield when rye-CC was managed properly with herbicides for weed control.

Previous studies have observed improvement in soil physical (Alhameid et al. 2020), biological (Alhameid et al. 2019) and chemical properties (Alhameid et al. 2017) with diverse rotations and NT system from the same experimental plots. Therefore, the true yield potential under cover cropping management may be hidden or influenced by resilience of long-term rotational and tillage system. We anticipate that NC plots reflect long-term characteristics of bare fallows as they have reached to steady-state conditions, however, CC plots reflect a transitional phase from conventional bare fallow to cover cropped systems. This alteration in management might influenced internal biogeochemical processes under CC soils. Tonitto et al. (2006) also emphasized that different temporal scales in the experiment may influence yield under the cover cropping system. It is assumed that as the number of CC years increase, soil quality would improve over time and thereby increase in corn and soybean yield can be expected (CTIC and SARE 2013).

Averaged across rotation and cover cropping management, tillage system affected corn yields (11.81 vs 11.23 Mg ha^{-1}, $P < 0.001$), whereas its effect was not significant for small grain yields (table 4). In addition, tillage by rotation interaction was observed for soybean yield ($P=0.003$), as NT had 9% greater yield than the CT system only under 2-yr rotation. The compromised corn yields under NT system could be attributable to prevalent wetter soil conditions during the spring or early summer in heavy-textured soils of the South Dakota. The amount of residue retention under NT on the soil surface was greater than that under CT system. This can lead to interference in seed germination, delay in plant emergence and development due to less light interception with correspondingly colder soil temperatures coupled with wet conditions (Sindelar et al. 2013; Hatfield 2014). Therefore, the reduced plant response at early crop growth stages might results in lower biomass production and thereby relatively less grain yield under the NT system. Corn yield reduction under NT was also documented in similar environments in Iowa by Al-Kaisi et al. (2015) and in Minnesota by Vetsch et al. (2007), whereas, improvement of soybean yield with NT compared to CT when rotated with corn is in agreement with Pedersen and Lauer (2003) in Wisconsin soils. Unlike corn, soybean is not an N responsive crop. So, there could be an argument that N fertilized during planting of NT-corn might immobilized by microbes while decomposing the previous crop residues. Hence, poor synchrony between mineralized and plant available N might affect corn performance whereby, this effect might not apply to the NT-soybean because of biological nitrogen fixation. Hence, our study supports the findings of Wade et al. (2015) that choice of tillage depends on crop in practice, where NT system is more advantageous for soybeans than corn.

Furthermore, winter wheat yield during the study period, on an average, was 8% greater under CT than the NT system (4.43 vs 4.09 Mg ha^{-1}**)**, however, the effect was not statistically different (P= 0.076). Overall, our results showed agreement with DeFelice et al. (2006) findings where they concluded that NT tends to generate higher yield in regions with high temperature and/or limited rainfall, but lower yields in Northern United States and areas where soils are poorly drained.

Overall Production Costs. Production costs varied among the various crops with the highest total cost associated with corn, followed by soybean (table 5). Small grains had the lowest production costs, which were about half or less than half of the costs associated with corn production. Therefore, averaged across tillage and cover crops, total costs were significantly greater for the 2-yr systems than for the 3- and 4-yr systems, which could be attributed to relatively higher seed costs, and more fertilizer and pesticides input utilized for corn and soybeans than for the small grains (table 6). Stanger et al. (2008a) reported similar findings with corn having the highest costs. In addition, the total production costs in each NT system was about US$ 40 ha^{-1} lower than the tillage system due to the saved costs from fall chisel ploughing and spring field cultivation (table 6).

Cover cropping increased production costs because of the additional expenses in CC establishment (table 6). The additional expenses related to CC establishment consisted of the cost for seed, planting, and termination. The broadleaf blend (only in 3- and 4-yr rotations) had higher seed costs due to their biological traits, however, establishment costs for winter rye (after corn harvest in every rotation) was greater because of higher herbicides applied to terminate CC and control weed for soybean crop (table 5). On average, establishment cost for CC was similar under the 2- and 4-yr rotation (~ US$ 97 ha^{-1}), which was about ~US$ 29 ha^{-1} less than 3-yr rotation (table 6). The cost incurred for 3-yr rotation was greater due to the increased frequency of CC, as CC was planted once in 2-yr rotation cycle but twice in 3- and 4-yr rotation cycles. Averaged over all the cropping systems, cost of herbicide represents 10% of the expenditure costs in this study.

Management Effects on Net Returns. As no interaction was found between experimental factors (rotation, tillage, and cover cropping) ($P > 0.05$) for overall gross revenue, BCRs and net return, therefore, pairwise comparison between management factors were conducted. As demonstrated in table 6, the 2-yr rotation resulted in higher total gross revenue and net returns as compared to those with 3- and 4-yr rotations. This is mainly due to the lower gross revenue of small grains contained in the 3- and 4-year rotations, where oat and winter wheat only produced about 45% to 50% of the gross revenue generated by corn and soybeans. Our results agreed with other Midwest US Corn Belt studies (Chase et al. 2016; Nafziger 2009), those who demonstrated that the profitability from small grains themselves is likely lower than for corn or soybeans. Others have related lower profits to production challenges to small grain yield and market options (Weisberger 2017; Larsen 2015). Nevertheless, diversity created with small grains in 3- and 4-yr rotations partially pays off by increasing net returns from the corn and soybean enterprises. Averaged over tillage and cover cropping systems, both corn and soybean profits increased with 4-yr rotation by 12% and 9% as compared to the 2-yr rotation (table 7). These differences are caused by greater corn and soybean yields with diversified rotations as discussed earlier in crop yield section. Note that other benefits from diversified rotations such as weed suppression, small-gains straw value or N credit were not considered in our study, which would increase the net returns for the 3- and 4-yr rotations. For instance, a study conducted by Liebman et al. (2008) in Iowa found that net returns were highest for the 4-yr (corn-soybean-small grain/alfalfa -alfalfa), lowest for the 3-yr [corn-soybean-small grain/red clover (*Trifolium pratense* L.)], and intermediate for the 2-yr rotation. This is partly due to the reduced use of synthetic N fertilizer and herbicide in diversified crop rotations (3-and 4-yr), which in comparison with 2-yr rotation were reduced by 59% and 76% in the 3-yr rotation and 74% and 82% in the 4-yr rotation, respectively.

One of the important functions of small grains in Midwest cropping systems is to provide a window for establishment of forage legume such as alfalfa (*Medicago sativa* L.) and clover. The legume stands, after being terminated, bring fertilizer replacement value for corn establishment, which can easily overcome their cost of establishment. In our study, however, there was no forage legume and production of both oat and winter wheat were reliant on synthetic N fertilizer. So, operating cost of producing small grains was still higher to what reported by other studies (e.g. Vocke and Ali 2013; Liebman et al. 2008), however they were relatively much less than corn and soybean in the present study (table 5 and 6). In this study, we did not account for any oat/wheat straw value and only grains were included in our economic calculations. Therefore, producers who use 3- and 4-yr rotations will likely obtain higher economic returns than our reported values by obtaining feed value to straw and/or utilizing small grains for grazing purpose. In addition, we used average annual commodity prices for oat and winter wheat, which could be less than for the producers who sell their small grains produce directly to the grain-mills or receive contractual payment. Nevertheless, as with adopting any new agricultural practice, our study suggests that adding a small grain to a corn-soybean cropping system should be an incremental step, starting with one small grains crop. This is reflected from similar BCRs between 2- and 3-yr rotations (1.62 vs 1.60) (table 6).

Our study shows that average net returns for plots with CC were lower than those plots without CC (table 6), due to additional CC expenses in combination with no improvement in corn and soybeans yields. This result is consistent with Plastina et al. (2018) finding that CC generates lower net returns than the NC in the short term unless it is used for on-farm benefits such as grazing livestock (Tobin et al. 2020), or cost-share payments are received, both of which are not accounted for in our study. The latter part is even more important for producers who are at the beginning stage of experimenting with growing CC in their fields. As CC in our experiment has only been introduced for a short-term (5 years), their immediate economic impact was not expected. However, it is noteworthy that on average the 2-yr NT system with winter rye as CC generates the highest gross revenue and second-best net returns among all studied systems in our study (table 6). This gives an important indication for producers who are new to cover cropping. Compared to 3- and 4-yr rotations, incorporating CC in 2-yr rotation in combination with NT will provide producers an economically feasible alternative option to diversify the system.

Tillage did not affect net return of corn and oat but had a significant impact on soybean and winter wheat profits (table 7). Averaged over rotation and cover cropping management, the NT plots generated an increase in soybean profitability by 10.4% as compared to the CT plots. A significant interaction suggests that greater net return for soybean in the NT than CT system was only achieved under the 2-yr rotation. When analyzed over the whole experiment, gross revenue, and net returns for the NT system in this study were similar on average to the CT system (table

6). Other conditions the same, systems under NT always generated higher BCRs than those under CT. In addition to associated soil conservation benefits (Karlen et al. 2013; Archer and Reicosky 2009), our study also support the viewpoint that NT system provides an economically more sustainable option than CT system because of the greater economic returns in general and improved BCRs.

Summary and Conclusions

The economic performance of twelve cropping systems that include a combination of three rotations (corn-soybean, corn-soybean-oat, and corn-soybean-oat-winter wheat), two tillage systems (no-till vs. conventional-till) and two cover (with and without cover crops) cropping treatments was calculated from a long-term study established in 1991 (cover crops introduced in fall 2013). The grain yield and commodity price data for 5-yr under all the studied cropping systems was collected and analyzed. This study showed that crop yield and profit from corn and soybean phases increased as the rotations became more diversified with small grains (oats and winter wheat). Further, this study also demonstrates the yield and economic insights of integrating cover crops such as blend of legumes and brassicas after small grains, and winter rye after the corn harvest. While CC in its short-term did not contribute to economic benefit in our experiment, our results indicate that incorporating CC in 2-yr rotation under NT treatment will provide producers an economically feasible option to diversify the system. In this study, NT system increased soybean yield but compromised the yields of corn. Even so, due to the reduced cost, NT generated economically equivalent returns as compared to the CT but improved the BCRs. Although we observed soil quality benefits from the conservation practices during this long-term experimental study (Alhameid et al. 2017; Alhameid et al. 2020; Singh and Kumar

2020), in the context of overall profitability, the diversified cropping system in this study lagged behind the traditional corn-soybean 2-yr system which could be attributed to the relatively lower profits and more yield variation from small grains as compared to the corn and soybean crops. Therefore, it is important to include more profitable crops such as forage legumes that are both beneficial for soils and the environment in the diversified rotations and integrate CC with livestock to compensate the production cost. The CC results from present study should be interpreted with caution as period of analysis was relatively short (5 years) and included only above-average rainfall years. Additionally, the present study did not consider the potential economic implications such as fertilizer N credit, forage or straw value from cover crop or small grains and weed suppression under the diverse cropping system.

References

Al-Kaisi, M.M., S.V. Archontoulis, D. Kwaw-Mensah, and F. Miguez. 2015. Tillage and crop rotation effects on corn agronomic response and economic return at seven Iowa locations. Agronomy Journal 107(4): 1411-1424.

Alhameid, A., M. Ibrahim, S. Kumar, P. Sexton, and T. Schumacher. 2017. Soil organic carbon changes impacted by crop rotational diversity under no-till farming in South Dakota, USA. Soil Science Society of America Journal 81(4): 868-877.

Alhameid, A., J. Singh, U. Sekaran, S. Kumar, and S. Singh (2019). Soil biological health: Influence of crop rotational diversity and tillage on soil microbial properties. Soil Science Society of America Journal 83(5): 1431-1442.

Alhameid, A., J. Singh, U. Sekaran, E. Ozlu, S. Kumar, and S. Singh. 2020. Crop rotational diversity impacts soil physical and hydrological properties under long-term no-and conventional-till soils. Soil Research 58(1): 84-94.

Anderson, R.L. 2005. Improving sustainability of cropping systems in the central Great Plains. Journal of Sustainable Agriculture 26(1): 97-114.

Anderson, R.L. 2016. Increasing corn yield with no-till cropping systems: A case study in South Dakota. Renewable Agriculture and Food Systems 31(6): 568-573.

Archer, D.W., M.A. Liebig, D.L. Tanaka, and K.P. Pokharel. 2018. Crop diversity effects on productivity and economics: A Northern Great Plains case study. Renewable Agriculture and Food Systems: 1-8.

Archer, D.W., and D.C. Reicosky. 2009. Economic performance of alternative tillage systems in the northern Corn Belt. Agronomy Journal 101(2): 296-304.

Bauer, T.L. 1991. Use of the allelopathic and mulch properties of rye as a method of weed control in soybean. Master's thesis, University of Wisconsin, Madison.

Blanco, H., and R. Lal. 2010. Principles of Soil Conservation and Management. Dordrecht: Springer.

Chase, C., M. Smith, and K. Delate. 2016. Organic crop production enterprise budgets. Iowa State University-Extension and Outreach. http://www.extension.iastate.edu (accessed 2 Nov. 2016).

Chatterjee, A., K. Cooper, A. Klaustermeier, R. Awale, and L. J. Cihacek. 2016. Does crop species diversity influence soil carbon and nitrogen pools? Agronomy Journal 108(1): 427-432.

Cornelius, C.D., and K.W. Bradley. 2017. Carryover of common corn and soybean herbicides to various cover crop species. Weed Technology 31(1): 21-31.

CTIC, and SARE. 2013. 2012–2013 cover crop survey.

Daigh, A.L., W.A. Dick, M.J. Helmers, R. Lal, J.G. Lauer, E. Nafziger, C.H. Pederson, J. Strock, M. Villamil, and A. Mukherjee. 2018. Yields and yield stability of no-till and chisel-plow fields in the Midwestern US Corn Belt. Field Crops Research 218: 243-253.

Davis, A.S., J.D. Hill, C.A. Chase, A.M. Johanns, and M. Liebman. 2012. Increasing cropping system diversity balances productivity, profitability and environmental health. PloSOne 7(10): e47149.

De Bruin, J.L., P.M. Porter, and N.R. Jordan. 2005. Use of a rye cover crop following corn in rotation with soybean in the upper Midwest. Agronomy Journal 97(2): 587-598.

Delate, K., and C.A. Cambardella. 2004. Agroecosystem performance during transition to certified organic grain production. Agronomy Journal 96(5): 1288-1298.

Delgado, J.A., and C.J. Gantzer. 2015. The 4Rs for cover crops and other advances in cover crop management for environmental quality. Journal of Soil Water Conservation 70(6): 142A-145A.

Dick, W.A., D. Van Doren Jr, G. Triplett Jr, and J. Henry.1986. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters: II. Results obtained for a typic Fragiudalf soil. Research Bulletein 1180. Ohio Agricultural Research and Development Center, The Ohio State University, Columbus.

Dunn, M., J. Ulrich-Schad, L. Prokopy, R. Myers, C. Watts, and K. Scanlon. 2016. Perceptions and use of cover crops among early adopters: Findings from a national survey. Journal of Soil Water Conservation 71(1): 29-40.

Finney, D.M., E.G. Murrell, C.M. White, B. Baraibar, M.E. Barbercheck, B.A. Bradley, S. Cornelisse, M.C. Hunter, J.P. Kaye, and D.A. Mortensen. 2017. Ecosystem services and disservices are bundled in simple and diverse cover cropping systems. Agricultural & Environmental Letters 2(1).

Fowler, D.B. 2012. Wheat production in the high winter stress climate of the Great Plains of North America—An experiment in crop adaptation. Crop Science 52(1): 11-20.

Gaudin, A.C.M., T.N. Tolhurst, A.P. Ker, K. Janovicek, C. Tortora, R.C. Martin, and W. Deen. 2015. Increasing crop diversity mitigates weather variations and improves yield stability. Plos One 10(2).

Gaudin, A.C.M., S. Westra, C.E.S. Loucks, K. Janovicek, R.C. Martin, and W. Deen. 2013. Improving resilience of northern field crop systems using inter-seeded red clover: A review. Agronomy 3(1): 148.

Götze, P., J. Rücknagel, M. Wensch-Dorendorf, B. Märländer, and O. Christen. 2017. Crop rotation effects on yield, technological quality and yield stability of sugar beet after 45 trial years. European Journal of Agronomy 82: 50-59.

Hairston, J., J. Sanford, J. Hayes, and L. Reinschmiedt. 1984. Crop yield, soil erosion, and net returns from five tillage systems in the Mississippi Blackland Prairie. Journal of Soil Water Conservation 39(6): 391-395.

Hammel, J.E. 1995. Long-term tillage and crop rotation effects on winter wheat production in northern Idaho. Agronomy Journal 87(1): 16-22.

Hatfield, J.L. 2014. Radiation use efficiency: Evaluation of cropping and management systems. Agronomy Journal 106(5): 1820-1827.

Haugen, R. 2016. Custom farm work rates on North Dakota farms. North Dakota State University Extension Service.

Heck, R.J., B. Deen, L.J. Munkholm, and R.J. Heck. 2013. Long-term rotation and tillage effects on soil structure and crop yield. Soil and Tillage Research 127: 85-91.

Himanshu, S. K., A. Pandey, B. Yadav, and A. Gupta. 2019. Evaluation of best management practices for sediment and nutrient loss control using SWAT model. Soil and Tillage Research 192: 42-58.

Hunter, M.C., M.E. Schipanski, M.H. Burgess, J.C. LaChance, B.A. Bradley, M.E. Barbercheck, J.P. Kaye, and D.A. Mortensen. 2019. Cover crop mixture effects on maize, soybean, and wheat yield in rotation. Agricultural & Environmental Letters 4(1).

Kabir, Z., and R. Koide. 2002. Effect of autumn and winter mycorrhizal cover crops on soil properties, nutrient uptake and yield of sweet corn in Pennsylvania, USA. Plant and Soil 238(2): 205-215.

Karlen, D.L., C.A. Cambardella, J.L. Kovar, and T.S. Colvin. 2013. Soil quality response to long-term tillage and crop rotation practices. Soil and Tillage Research 133: 54-64.

Katsvairo, T.W., and W. J. Cox. 2000. Economics of cropping systems featuring different rotations, tillage, and management. Agronomy Journal 92(3): 485-493.

Krupinsky, J.M., D.L. Tanaka, S.D. Merrill, M.A. Liebig, and J.D. Hanson. 2006. Crop sequence effects of 10 crops in the northern Great Plains. Agricultural Systems 88(2): 227-254.

Larsen, D. 2015. Capturing indigenous knowledge of small grain production. Leopold Center Completed Grant Reports. 489. http://lib.dr.iastate.edu/leopold_grantreports/489

Lee, S., and L. McCann. 2019. Adoption of cover crops by US soybean producers. Journal of Agricultural and Applied Economics 51(4): 527-544.

Liebman, M., L.R. Gibson, D.N. Sundberg, A.H. Heggenstaller, P.R. Westerman, C.A. Chase, R.G. Hartzler, F.D. Menalled, A.S. Davis, and P.M. Dixon. 2008. Agronomic and economic performance characteristics of conventional and low-external-input cropping systems in the central Corn Belt. Agronomy Journal 100(3): 600-610.

Maiga, A., A. Alhameid, S. Singh, A. Polat, J. Singh, S. Kumar, and S. Osborne. 2019. Responses of soil organic carbon, aggregate stability, carbon and nitrogen fractions to 15 and 24 years of no-till diversified crop rotations. Soil Research 57(2): 149-157.

Mbuthia, L.W., V. Acosta-Martínez, J. DeBruyn, S. Schaeffer, D. Tyler, E. Odoi, M. Mpheshea, F. Walker, and N. Eash. 2015. Long term tillage, cover crop, and fertilization effects on microbial community structure, activity: Implications for soil quality. Soil Biology and Biochemistry 89: 24-34.

Meyer-Aurich, A., K. Janovicek, W. Deen, and A. Weersink. 2006. Impact of tillage and rotation on yield and economic performance in corn-based cropping systems. Agronomy Journal 98(5): 1204-1212.

Mosquera, V., J. Delgado, J. Alwang, L. López, Y. Ayala, J. Andrade, and R. D’Adamo. 2019. Conservation agriculture increases yields and economic returns of potato, forage, and grain systems of the Andes. Agronomy Journal 111(6): 2747-2753.

Nafziger, E. 2009. Small grains and grain sorghum. Illinois Agronomy Handbook. 24th ed. University of Illinois at Urbana Champaign, Urbana, IL: 37-47.

O'Brien, P.L., J.L. Hatfield, C. Dold, E.J. Kistner-Thomas, and K.M. Wacha. 2019. Cropping pattern changes diminish agroecosystem services in North and South Dakota, USA. Agronomy Journal doi: 10.1002/agj2.20001.

Pedersen, P., and J.G. Lauer. 2003. Corn and soybean response to rotation sequence, row spacing, and tillage system. Agronomy Journal 95(4): 965-971.

Philip Robertson, G., K.L. Gross, S.K. Hamilton, D.A. Landis, T.M. Schmidt, S.S. Snapp, and S.M. Swinton. 2014. Farming for ecosystem services: An ecological approach to production agriculture. BioScience 64(5): 404-415.

Pittelkow, C.M., X. Liang, B.A. Linquist, K.J. Van Groenigen, J. Lee, M.E. Lundy, N. Van Gestel, J. Six, R.T. Venterea, and C. Van Kessel. 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature 517(7534): 365.

Plastina, A., F. Liu, W. Sawadgo, F.E. Miguez, S. Carlson, and G. Marcillo. 2018. Annual net returns to cover crops in Iowa. Economics Working Papers 18005. Department of Economics, Iowa State University, Ames. https://lib.dr.iastate.edu/econ_workingpapers/39 (accessed 21 Mar. 2019).

Porter, P.M., D.R. Huggins, C.A. Perillo, S.R. Quiring, and R.K. Crookston. 2003. Organic and other management strategies with two- and four-year crop rotations in Minnesota. Agronomy Journal 95(2): 233-244.

Roesch-McNally, G.E., J. Arbuckle, and J.C. Tyndall. 2018. Barriers to implementing climate resilient agricultural strategies: The case of crop diversification in the US Corn Belt. Global Environmental Change 48: 206-215.

Sakurai, G., T. Iizumi, and M. Yokozawa. 2011. Varying temporal and spatial effects of climate on maize and soybean affect yield prediction. Climate Research 49(2): 143-154.

SAS Institute. 2011. Statistical analysis system. Cary, NC: SAS Institute.

Sindelar, A., J. Coulter, J. Lamb, and J. Vetsch. 2013. Agronomic responses of continuous corn to stover, tillage, and nitrogen management. Agronomy Journal 105(6):1498-1506.

Singh, J. 2020. Crop Rotations, Tillage and Cover Crops Influences on Soil Health, Greenhouse Gas Emissions and Farm Profitability. PhD dissertation, South Dakota State University.

Singh, J. and S. Kumar. 2020. Seasonal changes of soil carbon fractions and enzyme activities in response to winter cover crops under long-term rotation and tillage systems. European Journal of Soil Science https://doi.org/10.1111/ejss.13028.

Singh, J., N. Singh, and S. Kumar. 2020. X-ray computed tomography-measured soil pore parameters as influenced by crop rotations and cover crops. Soil Science Society of America Journal 84(1):1267-1279.

Smith, R.G., and K.L. Gross. 2006. Weed community and corn yield variability in diverse management systems. Weed Science 54(1):106-113.

Smith, R.G., K.L. Gross, and G.P. Robertson. 2008. Effects of crop diversity on agroecosystem function: Crop yield response. Ecosystems 11(3): 355-366.

Soule, M.J., A. Tegene, and K.D. Wiebe. 2000. Land tenure and the adoption of conservation practices. American Journal of Agricultural Economics 82(4): 993-1005.

Stanger, T.F., J.G. Lauer, and J.P. Chavas. 2008. The profitability and risk of long-term cropping systems featuring different rotations and nitrogen rates. Agronomy Journal 100(1): 105-113.

Sullivan, P.G., D.J. Parrish, and J.M. Luna. 1991. Cover crop contributions to N supply and water conservation in corn production. American Journal of Alternative Agriculture 6(3): 106-113.

Tobin, C., S. Singh, S. Kumar, T. Wang, and P. Sexton. 2020. Demonstrating short-term impacts of grazing and cover crops on soil health and economic benefits in an integrated crop-livestock system in South Dakota. Open Journal of Soil Science 10(03):109.

Tonitto, C., M.B. David, and L. Drinkwater. 2006. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. Agriculture, Ecosystems & Environment 112(1): 58-72.

USDA NASS. 2018. USDA National Agricultural Statistics Service https://www.nass.usda.gov/Statistics_by_State/.

Vetsch, J.A., G.W. Randall, and J.A. Lamb. 2007. Corn and soybean production as affected by tillage systems. Agronomy Journal 99(4): 952-959.

Vocke, G., and M. Ali. 2013. US wheat production practices, costs, and yields: Variations across regions. Economics Reserarch Service. Washington, DC: USDA.

Wade, T., R. Claassen, and S. Wallander. 2015. Conservation-practice adoption rates vary widely by crop and region, EIB-147, December 2015. Washington, DC: USDA Economic Research Service.

Wagger, M. 1989. Time of desiccation effects on plant composition and subsequent nitrogen release from several winter annual cover crops. Agronomy Journal 81(2): 236-241.

Wegner, B.R., K.S. Chalise, S. Singh, L. Lai, G.O. Abagandura, S. Kumar, S.L. Osborne, R.M. Lehman, and S. Jagadamma. 2018. Response of soil surface greenhouse gas fluxes to crop residue removal and cover crops under a corn–soybean rotation. Journal of Environmental Quality 47(5):1146-1154.

Weisberger, D. 2017. Production, perceptions and limitations of organic small grains in Iowa. Master’s thesis, Iowa State University.

Wilhelm, W., and C.S. Wortmann. 2004. Tillage and rotation interactions for corn and soybean grain yield as affected by precipitation and air temperature. Agronomy Journal 96(2): 425-432.

Table 1

Sequence of corn (C), soybean (S), oat (O), winter wheat (WW), winter rye (wr), and blend-cover crop (b) for the period from 2014 to 2018, Beresford, SD.

Treatment	Fall 2013	2014	2015	2016	2017	2018
2-yr CC*	wr†	S	C/wr	S	C/wr	S
2-yr NC	-	S	C	S	C	S
3-yr CC	wr	S	O/b	C/wr	S	O
3-yr NC	-	S	O	C	S	O
4-yr CC	wr	S	O	WW/b	C/wr	S
4-yr NC	-	S	O	WW	C	S

* 2-yr CC; corn-soybean rotation with cover crop (CC)
2-yr NC; corn-soybean rotation without cover crop (NC)
3-yr CC; corn-soybean-oats rotation with cover crop (CC)
3-yr NC; corn-soybean rotation-oats without cover crop (NC)
4-yr CC; corn-soybean-oats-winter wheat rotation with cover crop (CC)
4-yr NC; corn-soybean rotation-oats- winter wheat without cover crop (NC)

† Only a snippet of cropping sequence is shown here. In the study, each crop phase of each rotation system present every year in four replicate blocks.

Table 2

Planting rate, fertilizer application, weed control, and fungicide inputs for maize, soybeans, oats, winter wheat, winter rye, and blend at Beresford, SD, during the 2014 to 2018 growing seasons.

Crop input	Corn	Soybean	Oats	Winter wheat	Winter rye	Blend
Planting rate	78 000 seeds ha^{-1}	375 000 seeds ha^{-1}	87 kg ha^{-1}	132 kg ha^{-1}	56 kg ha^{-1}	28 kg ha^{-1}
Fertilizer						
Preplant	157 kg N ha^{-1}, 22 kg P ha^{-1}, and 64 kg K ha^{-1}	10 kg N ha^{-1}, 20 kg P ha^{-1}, and 64 kg K ha^{-1}	55 kg N ha^{-1}, 20 kg P ha^{-1}, and 64 kg K ha^{-1}	10 kg N ha^{-1}		
Sidedress	33 kg N ha^{-1}			138 kg N ha^{-1}, 20 kg P ha^{-1}, and 64 kg K ha^{-1}		
Herbicides						
Preemergence	1.01 kg ha^{-1} a.i. glyphosate + 1.07 ha^{-1} a.i. metolachlor + 0.18 kg ha^{-1} a.i. metribuzin + 0.02 kg ha^{-1} a.i. saflufenacil	1.01 kg ha^{-1} a.i. glyphosate + 1.07 ha^{-1} a.i. metolachlor + 0.18 kg ha^{-1} a.i. metribuzin + 0.02 kg ha^{-1} a.i. saflufenacil	0.78 kg ha^{-1} a.i. glyphosate	0.92 kg ha^{-1} a.i. glyphosate		0.92 kg ha^{-1} a.i. glyphosate
Postemergence	0.08 kg ha^{-1} a.i. mesotrione + 0.16 kg ha^{-1} a.i atrazine	1.01 kg ha^{-1} a.i. glyphosate + 0.14 kg ha^{-1} a.i. clethodim + 0.14 kg ha^{-1} a.i. fomesafen + 0.014 kg ha^{-1} a.i. cloransulam-methyl	0.46 kg ha^{-1} a.i. bromoxynil + 0.28 kg ha^{-1} a.i dicamba*	0.02 kg ha^{-1} a.i. pyroxsulam + 0.37 kg ha^{-1} a.i. bromoxynil + 0.28 kg ha^{-1} a.i dicamba		
Broadcast knockdown			0.92 kg ha^{-1} a.i. glyphosate	0.92 kg ha^{-1} a.i. glyphosate	1.01 kg ha^{-1} a.i. glyphosate + 1.07 ha^{-1} a.i. metolachlor + 0.18 kg ha^{-1} a.i. metribuzin + 0.02 kg ha^{-1} a.i. saflufenacil	
Fungicides†			0.12 kg ha^{-1} a.i. propiconazole	0.08 kg ha^{-1} a.i. metconazole		

*Dicamba was only applied to small grains in 2014.

† Fungicides were applied to small grains in 2015, 2016, and 2017.

Table 3

Influence of year on crop yield and growing season precipitation (Apr. to Sept.) and coefficient of variation in the long-term cropping system study at Beresford, SD, 2014-2018.

Year	**Corn**	**Soybean**	**Oats**	**Winter wheat**	**Precipitation**
		Yield, Mg ha^{-1}			**mm**
2014	10.8 c*	3.9 bc	3.1 d	2.4 b	559
2015	11.3 b	4.4 a	5.8 a	4.8 a	631
2016	11.6 b	3.8 cd	3.9 b	5.0 a	602
2017	10.5 c	3.7 d	3.9 b	5.0 a	581
2018	13.8 a	4.0 b	3.5 c	4.4 a	703
		Coefficient of variation (%)			
	14	13	27	28	

*Numbers in the same column followed by same letter are not statistically different from each other at the 0.05 significance level according to LS MEANS.

Table 4

Influence of rotation [corn-soybean (2-yr), corn–soybean–oats (3-yr), and corn–soybean–oats – winter wheat (4-yr)], tillage [no-till (NT) and conventional-till (CT)] and cover cropping [cover crops (CC) and no-cover crop (NC)] management on crop yield in the long-term cropping system study, Beresford, SD, 2014-2018. Within a column, different lowercase letters are significant at $p < 0.05$.

Sources of variation	**Corn**	**Soybean**	**Oats**	**Winter Wheat**
	Yield (Mg ha^{-1})			
Rotation				
2-yr	11.22 b	3.86	-	-
3-yr	11.47 b	3.99	4.11	-
4-yr	11.88 a	4.02	3.98	4.26
p-value	0.001	0.054	0.122	-
Tillage				
NT	11.23 b	3.99	4.00	4.09
CT	11.81 a	3.93	4.09	4.43
p-value	<0.001	0.320	0.269	0.076
Rotation x Tillage				
2-yr, NT	11.12	4.03 a	-	-
2-yr, CT	11.43	3.70 b	-	-
3-yr, NT	10.96	3.92 a	4.06	-
3-yr, CT	11.99	4.06 a	4.15	-
4-yr, NT	11.72	4.01 a	3.94	-
4-yr, CT	12.05	4.03 a	4.02	-
p-value	0.090	0.003	0.980	-
Cover cropping				
CC	11.38 b	3.91	-	-
NC	11.67 a	4.01	-	-
p-value	0.048	0.062	-	-

Table 5

Mean annual production cost structure of corn, soybean, oats, winter wheat, winter rye, and blend, 2014 to 2018 at Beresford, SD.

	Production costs (US$ ha^{-1})					
Input	**Corn**	**Soybean**	**Oats**	**Winter wheat**	**Winter rye**	**Blend**
Seed	228*	138	36	48	18	32
Fertilizer	297	71	117	188	-	-
Pesticides	65	82	25	23	43	8
Machinery†	147	137	110	153	41	41
Drying and Hauling‡	155	47	86	49	-	-
Crop insurance	64	40	25	36	-	-
Total cost	955	515	398	497	102	81

*All costs are rounded to the nearest dollar.

†Machinery expenses calculated using custom rates of North Dakota (Haugen, 2016).

‡Drying and hauling costs based on average yield in the study (corn; 11.5 t ha^{-1}, soybean; 3.96 t ha^{-1}, oats; 4.05 t ha^{-1}, winter wheat; 4.26 t ha^{-1}).

Table 6

Gross returns, production costs, net returns, and benefit-cost ratio (BCR) for corn-soybean (2-yr), corn–soybean–oats (3-yr), and corn–soybean–oats – winter wheat (4-yr) rotations with cover crops (CC) and no-cover crop (NC) under no-till (NT) and conventional-till (CT) systems, averaged across the 2014 to 2018 growing seasons in the long-term cropping system study at Beresford, SD. Within a column, different lowercase letters are significant at $p < 0.05$.

Rotation	**Tillage**	**Cover cropping**	**Gross returns**	**Production costs**	**Net returns**	**BCR**
				US$ ha^{-1}		
Rotation						
2-yr			1358 a	838 a	520 a	1.62 a
3-yr			1179 b	738 b	441 b	1.60 a
4-yr			1095 c	703 b	392 c	1.56 b
p-value			<0.001	<0.001	<0.001	0.008
Tillage						
	NT		1174	725 b	449	1.62 a
	CT		1193	766 a	427	1.56 b
	p-value		0.667	0.025	0.198	0.032
Cover cropping						
		CC	1171	773 a	398 b	1.52 b
		NC	1196	719 b	477 a	1.66 a
		p-value	0.381	0.004	<0.001	<0.001
Rotation x Tillage x Cover cropping						
2-yr	NT	CC	1380	837	543	1.65
	CT	CC	1320	886	434	1.49
	NT	NC	1375	790	585	1.74
	CT	NC	1359	836	524	1.69
3-yr	NT	CC	1126	745	381	1.51
	CT	CC	1191	793	398	1.50
	NT	NC	1172	682	490	1.72
	CT	NC	1226	730	496	1.68
4-yr	NT	CC	1080	713	366	1.51
	CT	CC	1092	741	351	1.47
	NT	NC	1096	663	433	1.65
	CT	NC	1112	695	417	1.60
	p-value		ns*	ns	ns	ns

*ns, not significant at $p < 0.05$.

Table 7

Influence of rotation [corn-soybean (2-yr), corn–soybean–oats (3-yr), and corn–soybean–oats – winter wheat (4-yr)], tillage [no-till (NT) and conventional-till (CT)] and cover cropping [cover crops (CC) and no-cover crop (NC)] management on crop associated net returns in the long-term cropping system study, Beresford, SD, 2014-2018. Within a column, different lowercase letters are significant at $p < 0.05$.

Sources of variation	**Corn**	**Soybean**	**Oats**	**Winter Wheat**
		US$ ha^{-1}		
Rotation				
2-yr	394 b	648	-	-
3-yr	393 b	693	207 a	-
4-yr	441 a	704	183 b	168
p-value	0.018	0.058	0.008	-
Tillage				
NT	402	717 a	205	146 b
CT	417	648 b	187	189 a
p-value	0.184	<0.001	0.156	0.001
Rotation x Tillage				
2-yr, NT	401	731 a	-	-
2-yr, CT	386	571 b	-	-
3-yr, NT	358	696 a	216	-
3-yr, CT	426	690 a	199	-
4-yr, NT	444	725 a	194	-
4-yr, CT	439	683 a	173	-
p-value	0.100	0.003	0.860	-
Cover cropping				
CC	364 b	614 b	-	-
NC	455 a	751 a	-	-
p-value	<0.001	<0.001	-	-
Rotation x Cover cropping				
2-yr, CC	396 b	578	-	-
2-yr, NC	391 b	720	-	-
3-yr, CC	317 c	619	-	-
3-yr, NC	468 a	767	-	-
4-yr, CC	379 b	645	-	-
4-yr, NC	504 a	763	-	-
p-value	<0.001	0.798	-	-