Long-term tillage and crop rotation effects on soil, yield and economic returns

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Summary

Corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) are major annual crops grown in yearly rotation in Iowa. The economic returns of both crops with different tillage systems and crop rotations are highly influenced by regional soil and climate conditions. This study was conducted at seven locations in Iowa from 2003 to 2013 with the objectives to: (i) investigate seasonal variability in corn and soybean yields as affected by tillage and crop rotation, (ii) identify appropriate tillage system for each crop rotation and location, and (iii) evaluate the magnitude of crop rotation effect on the yields and economic returns of both corn and soybean. The experiment design was split-plot with tillage as main plot treatment including five tillage systems (no-tillage, NT; strip-tillage, ST; chisel plow, CP; deep rip, DR; and moldboard plow, MP).Three crop rotations, corn–soybean, C–S; corn–corn–soybean, C–C–S; and corn–corn, C–C were the subplot treatments replicated four times in a completely randomized block design. Corn yields varied from 39.9 bu/acre to 252.0 bu/acre without detectable increase over time. Average corn yield in northern locations was 30.3 bu/acre higher than corn yields in the southern locations with an economic return advantage of $133/acre. Yield and economic returns advantage of the three rotations systems are as follow C-S> C-C-S> C-C. Yield and economic return penalty for NT were greater than conventional tillage in the northern locations with poorly-drained soils than the southern locations with well-drained soils. Corn yield penalty associated with C-C was location specific and varied from 11 to 28%. Soybean yields show no significant response to tillage systems at different locations and the economic return with NT ($509/acre) exceeded that with conventional tillage ($502/acre). Input costs excluding land rental and crop insurance were lower with NT ($187/acre) than with conventional tillage ($207/acre). The C-C-S rotation resulted in greater soybean yields (9%) and economic returns (11%) than the C-S rotation in five out of the seven locations. The rotation effect of C-S, C-C-S was consistently higher in the southern locations (well-drained soils and warmer temperature) than northern locations (poorly-drained soils and cooler temperatures). Site specific effects of rotation on soybean yield were greater than tillage system. Across all the locations, the average economic return per acre for C-S rotation ($388) was 14% higher than C-C-S rotation ($333) and 41% higher than the C-C rotation ($227) showing a stable economic return over time for soybean in C-C-S rotation.

Introduction

Corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) are two major crops grown in Iowa in yearly rotations with different tillage systems. Iowa leads in corn and soybean production in the United States, which is the world's largest producer and exporter of corn, exporting between 10 to 20 percent of its annual corn production (USDA-ERS, 2016) and 30% of the world's total soybean production (USDA-National Agriculture Statistics Service, 2014). In 2015, Iowa produced 520,460 bushels of soybean, which was approximately 13.4% of the total soybean (3,887,721 bushels) produced in the United States in 2015. Like corn, numerous studies have shown decreasing soybean yield when grown continuously as a monocrop rather than in rotation with cereal crops (Crookston et al., 1991; Meese et al., 1991; West et al., 1996). Therefore, there is a general consensus that crop rotation increases corn and soybean yield and economic return (Gentry et al., 2013; Karlen, et al., 2013; Pedersen and Lauer, 2004; Kelly et al., 2003).

However, the length and type of crop rotation can affect the rotation benefits for corn and soybeans. In Iowa, results from a 32-yr corn experiment only showed a small yield increase over time with a large year-to-year variability (Karlen et al., 2013). In Wisconsin, Pedersen and Lauer (2002, 2003) reported that soybean yield in annual rotation with corn averaged 7% lower than soybean yield after five years of continuous corn production. Other factors including different tillage systems also impact soybean yield through changes in the soil water content and temperature (Licht and Al-Kaisi, 2005) (Figure 1). Corn and soybean responses to different tillage systems and crop rotations is complex and also influenced by soil conditions including the drainage class, soil texture, soil organic matter, water holding capacity of the soil and weather conditions such as the amount of precipitation, temperature and frost-free days (DeFelice, 2006; Grassini et al., 2014). Therefore, farmers are interested in how different crop rotations and tillage systems affect corn and soybean yield. Studies have shown the short-term influence of tillage and crop rotation on crop productivity by changing the soil water and N dynamics (Gentry et al., 2013) and in the long-term by affecting the soil organic matter content (Conant et al., 2007; Khan et al., 2007; Al-Kaisi et al., 2013) (Figure 2).

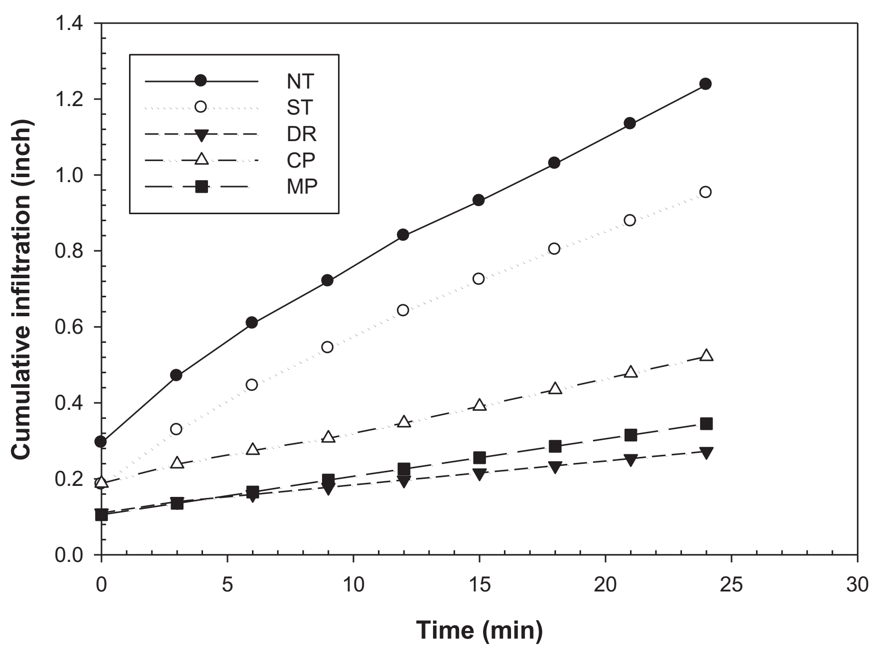

Figure 1. Cumulative water infiltration under five tillage systems. NT=no-till; ST=strip-tillage; CP=chisel plow; DR=deep rip; MP=moldboard plow

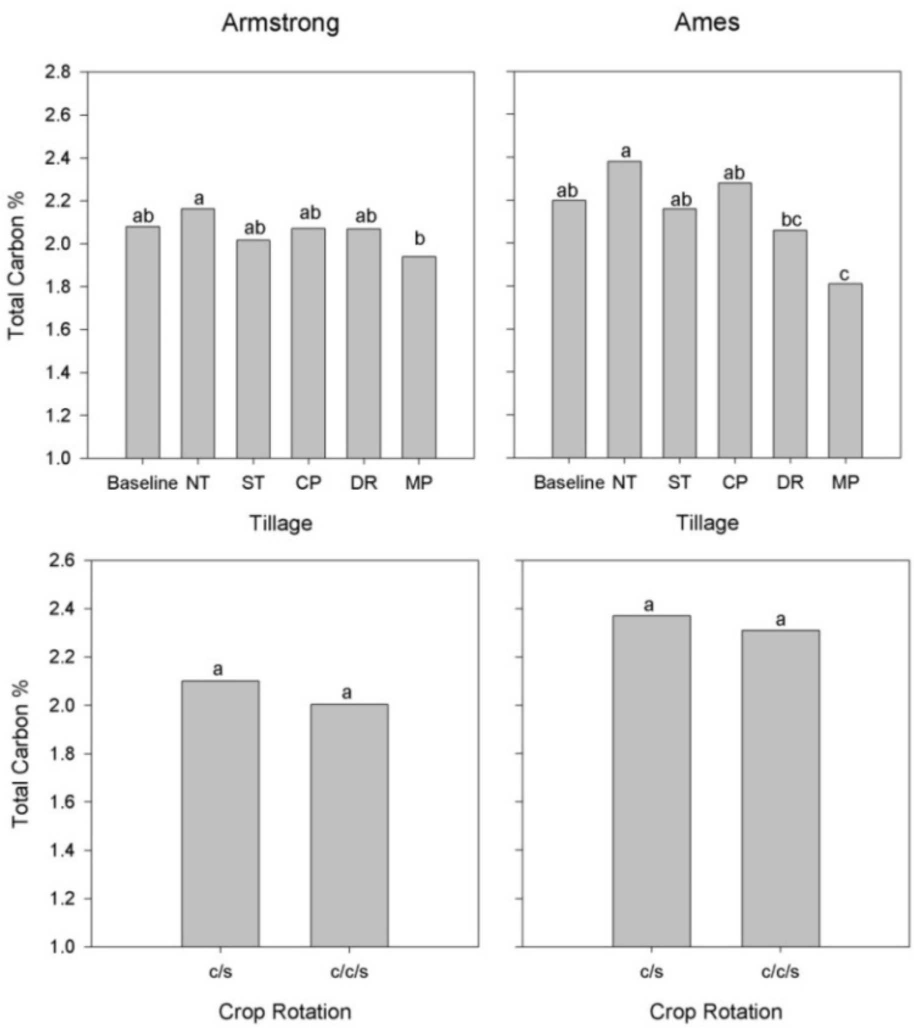

Figure 2. Tillage and crop rotation effects on soil organic carbon. (NT=no-till, ST=strip-tillage, CP=chisel-plow, DR=deep-rip, and MP=moldboard-plow).

The choice of crop rotation and tillage systems adopted in a particular location has soil health and environmental implications including the amount of crop residue that remains in the field after harvest. In the United States, areas with low annual rainfall and low soil water-holding capacity have generally demonstrated the advantages of conservation over conventional tillage systems (Wang et al., 2006; Hansen et al., 2012). However, there is variability in the effects of tillage and crop rotation on corn and soybean yield across years and locations (Manley et al., 2005; Halvorson et al., 2006; Endale et al., 2008; Toliver et al., 2012). In order to understand the changes in corn and soybean yield, it is important to consider the site-specific and spatial variability effects on the growth and yield responses of crops to different cropping systems including crop rotations and tillage systems (Guastaferro et al., 2010; Basso et al., 2007; Ribera et al., 2004; Bachelor et al., 2002). Furthermore, grain price and the desire of farmers to reduce production costs in addition to site-specific and spatial variability also influence the choice of management strategies for corn and soybean production (Guastaferro et al., 2010; Stanger et al., 2008; Meyer-Aurich et al., 2006). There is also the issue of farmers' confidence in the adoption of any new technology or management practice, which will potentially increase if it can be demonstrated that the new technology or management practice will be profitable over time. The objectives of this study that was published in the Agronomy Journal (Al-Kaisi et al., 2015 and Al-Kaisi et al., 2016) were to: i) investigate the seasonal variability of corn and soybean yields as affected by five tillage systems and three crop rotations and their interactions at each location ii) identify appropriate tillage systems for each crop rotation and location by evaluating multiple criteria such as corn and soybean yields, input costs and economic returns and iii) evaluate the magnitude of the rotation effect on corn and soybean yield and economic return at each location.

Experiment locations, weather information and design

The experiments for this long-term tillage and crop rotation study are established at seven Iowa State University research and demonstration farms that represent different soil associations and precipitation distribution across Iowa. The names, geographic locations and soil type information of the experiment locations which cover the major soil associations in the state and capture landscape differences are summarized in Table 1. The top soils of all locations of the experiment are characterized by high organic matter content in the range of 3.5 to 5.5%. Weather data including precipitation and air temperature from local weather stations at each location was used to determine precipitation and growing degree days (GDD). Growing degree days [base temperature 50oF (10°C)], cumulative annual precipitation, and growing season precipitation (from June 1st to September 15th) were calculated for each season at all locations and presented in Figure 3.

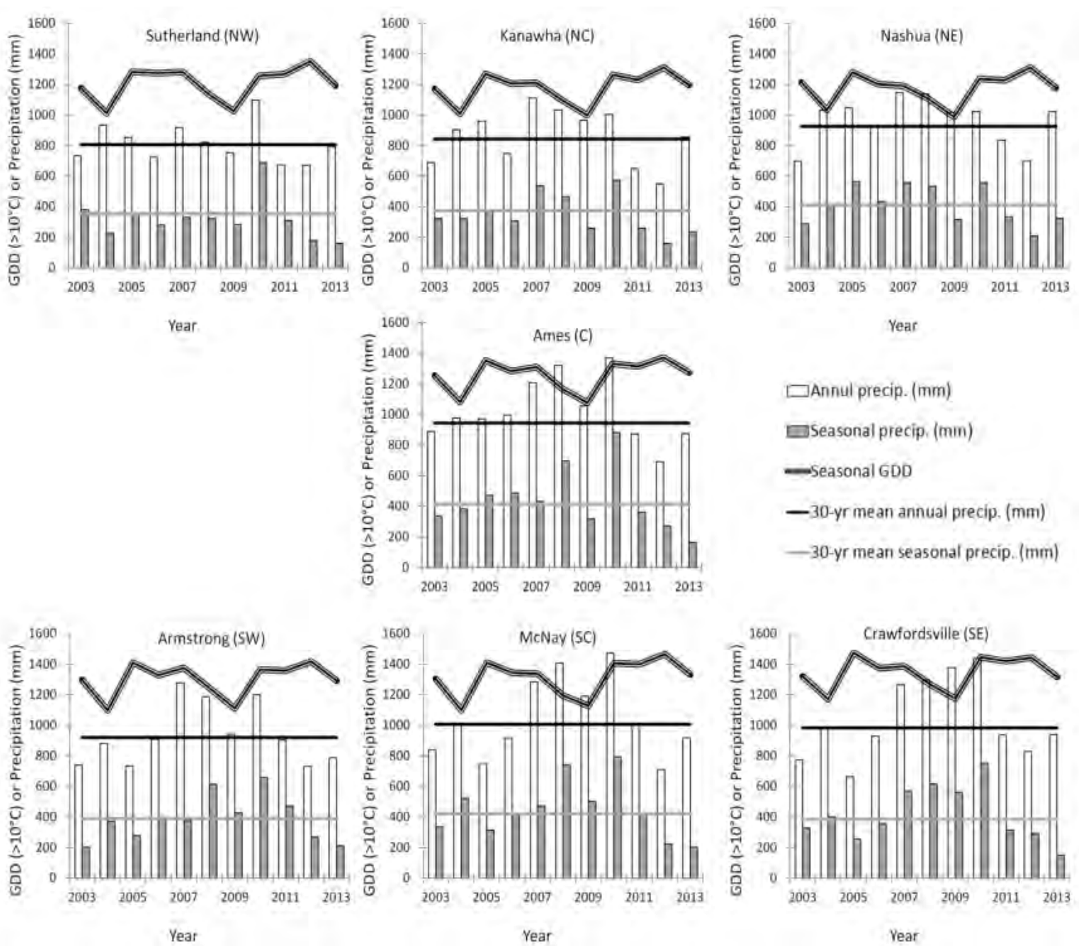

Figure 3. Seasonal growing degree days (GDD, base temperature of 10°C (50oF) from June 1st to September 15th), seasonal precipitation, annual precipitation, 30-yr mean annual precipitation, 30-yr mean seasonal precipitation for each location in Iowa.

Table 1. Major soil information by region across Iowa for all locations (USDA-NRCS, 2013).

Location†	Soil association	Soil series	Classification	Soil texture	Drainage Class
Ames (C)	Clarion-Nicollet-Webster	Nicollet	Fine-loamy, mixed, superactive, mesic Aquic Hapludolls	Clay loam	Somewhat poorly-drained
Crawfordsville (SE)	Otley-Mahaska-Taintor	Nira	Fine-silty, mixed, superactive, mesic Aquic Argiudolls	Silty clay loam	Moderately-well-drained
		Taintor	Fine, smectitic, mesic, Vertic Argiaquolls	Silty clay loam	Poorly-drained
Kanawha (NC)	Clarion-Nicollet-Webster	Webster	Fine-loamy, mixed, superactive, mesic Typic Endoaquolls	Silty clay loam	Poorly-drained and moderately permeable
Armstrong (SW)	Marshall	Marshall	Fine-silty, mixed, superactive, mesic Typic Hapludolls	Silty clay loam	Well-drained
McNay (SC)	Grundy-Haig	Grundy	Fine, smectitic, mesic Aquertic Argiudolls	Silt loam	Somewhat poorly-drained
		Haig	Fine, smectitic, mesic Vertic Argiaquolls	Silt loam	Poorly drained
Nashua (NE)	Kenyon-Floyd-Clyde	Kenyon	Fine-loamy, mixed, superactive, mesic Typic Hapludolls	Loam	Moderately well-drained
Sutherland (NW)	Galva-Primghar-Sac	Galva	Fine-silty, mixed, super-active, mesic Typic Hapludolls	Silty clay loam	Well-drained
		Primghar	Fine-silty, mixed, superactive, mesic Aquic Hapludolls	Silty clay loam	Somewhat poorly-drained

† Ames (Central Iowa); Crawfordsville (Southeast Iowa); Kanawha (North central Iowa); Armstrong (Southwest Iowa); McNay (South central Iowa); Nashua (Northeast Iowa); Sutherland (Northwest Iowa).

The experiments were established in 2003 at each location with a split-plot design in a completely randomized block with four replications. Treatments include five tillage systems and three crop rotations. The five tillage systems, no-tillage (NT), strip-tillage (ST), chisel plow (CP), deep rip (DR) and moldboard plow (MP) were randomly assigned within each replication as main plot treatments. The three crop rotations of corn-soybean (C-S), corn-corn-soybean (C-C-S) and continuous corn (C-C) were randomly assigned within each tillage systems as sub-plot treatments. The appearance of the corn-phase in the experiment was dictated by the type of rotation (i.e. in C-S, corn appeared every other year, in C-C-S, corn appeared every two consecutive years , and in C-C, corn appeared every year). At the Nashua location, there were two sets of the C-S and C-C-S rotations but only one set of C-S and two sets of C-C-S rotations at all other locations within each replication. The C-C treatment was added to all locations by converting one of the two sets of the C-C-S rotation in each replication to C-C in 2008. The dimensions of plots at all locations ranged between 30 to 90 ft long and 60 to 114 ft wide depending on the orientation of corn rows at each location and replications are separated by 27 to 50 ft borders. The same tillage operations for every tillage treatment were conducted every fall at each location of the experiment since the establishment of the study in 2003. No-tillage, in this study, is defined as the typical no pre-plant disturbance of the soil, except when corn was planted directly with the residue from the previous crop at the soil surface using a single coulter to cut through the residue along with a set of residue cleaners to remove residue to the side clearing 6 inch soil zone ahead of a standard planting unit. The CP treatment was implemented with a commercially available model mounted on a tool bar with straight shanks and twisted chisel plow sweeps at the bottom. The shanks were mounted on four tool bars in a staggering order to ensure an effective spacing of 15 inch between shanks for 8-10 inch tillage depth. The ST treatment was 8 inch deep, established with an anhydrous mole knife centered between two cover disks 8 inch apart. The tilled zone was 8 inch wide and 6-8 inch deep in close proximity to the previous row. The DR treatment was established with a commercially available model with four straight shanks spaced at 30 inch apart on a 9 ft. long mounted tool bar. The effective tillage depth of the DR treatment with the straight shanks was 18 inch. The MP treatment, which resulted in a complete inversion of the soil surface with nearly 100% incorporation of crop residue, was also established with a commercially available model with four full bottoms, 18 inch wide and 10 inch deep. All tillage treatments, except NT and ST received spring field cultivation 6 inch deep prior to planting.

Corn and soybean management

On average, corn planting dates across all experiment locations and years ranged between April 3 and May 21 of each growing season depending on weather conditions during the planting season. The row spacing in all corn experiments was 2.5 ft at a planting density of approximately 32,000-34,000 plants per acre. The relative maturity of corn hybrids ranged from 101-105 days in the northern locations to 109 -112 days in the southern locations. The N fertilization rates for all corn experiments were determined by using the N-rate calculator (Sawyer et al., 2006), which ranged from 130 lb N/acre for corn following soybean in the C-S and C-C-S rotations to 169 lb N/acre for corn following corn in the C-C-S and C-C rotations. Corn grain was harvested from the center four rows of each plot with a commercial four-row combine equipped to determine harvested grain weight and moisture content simultaneously. The reported corn yields were adjusted to a moisture content of 15.5 %.

Soybean was planted at the average planting density of 160,000 to 180,000 plants per acre. On average across all experimental locations and years, soybean planting occurred in between May 1 and May 15 of each growing season. Soybean cultivars planted in the northern locations belong to maturity Group 2 and those planted in the southern locations belong to Group 3. The only fertilizer applied in the soybean experiments every season based on soil test recommendations (Mallarino, 2002) was P as P_2O_5 (40 lb/acre) and K as K_2O (75 lb/acre). Soybean grain was harvested from the center six rows of each plot using a commercial six-row combine equipped to determine harvested grain weight and moisture content simultaneously. Soybean yields were calculated at 13.0% moisture content.

Economic analysis

The Ag Decision Maker (Duffy, 2014) was used to calculate economic returns (defined as the difference between gross income and input cost) of the various tillage systems and crop rotations for both crops in this study. The input cost included (i) pre-planting operations (ii) supplies (seeds, fertilizer and chemical), (iii) harvest (combine, haulage, drying and handling) and (iv) labor. In this analysis, land, crop insurance and liming costs were not included. These costs were the same across the research farms based on farm records kept by farm mangers and therefore had no effect on the outcome of the economic analysis. Gross income was estimated by multiplying the obtained grain yield for each treatment within each replication by the grain price based on USDA corn and soybean prices at the time of data analysis, which were $4.50/bushel for corn and $12.80/bushel for soybean. The time required by each field operation was based on Hanna (2001) using machine size of intermediate field capacity. Farm labor cost for operating machinery including spraying to control weed, pests and diseases or for harvesting was $14.90/ hour and $13.30/hour for other operations based on the Ag Decision Maker (Duffy, 2014). The labor cost was the actual fieldwork, the time for maintenance, travel and other activities related to corn and soybean production.

Results and discussion

Corn results: Temporal and spatial variability in corn yield

The results of corn yield are presented as Figures 4, 5, and 6. Over the 10-year period of the study (2003 to 2013), corn yields across the seven locations ranged from 108 bu/acre, at McNay research farm to 204 bu/acre at Nashua research farm. The poorly-drained high-clay content soil at the McNay farm without tiles contributed to the poor corn yield at that location. There were significant interactions effects between years, locations, and tillage systems on corn yields within the two rotations of C-S (P=0.02) and C-C (P=0.04). In the C-S rotation, corn yields with the conventional tillage systems (CP, DR and MP) were not significantly different from those with the ST system, but significantly different from NT yields in five out of the seven locations (Figure 4). The two exceptions were the southern locations of Armstrong and Crawfordsville, where the performance of all tillage systems was the same.

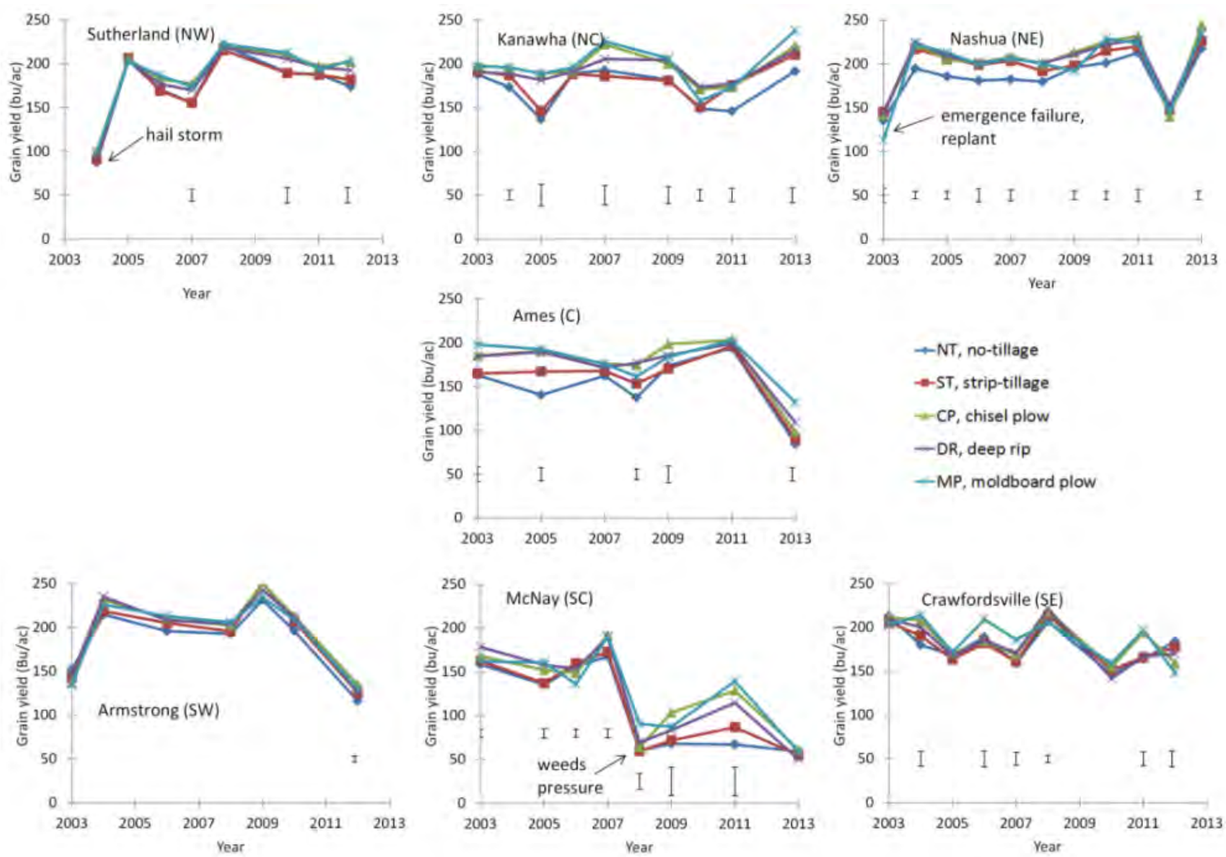

Figure 4. Effect of five tillage systems on temporal variation in corn yield in a corn-soybean (C-S) across seven locations in Iowa. Vertical bars where visible, indicate the two times standard errors of difference between tillage systems at $P<0.05$. CV is the coefficient of variation.

In the C-C-S rotation, there was no significant interaction effect on yield between location and tillage where conventional tillage systems yields were 11% greater than those with NT at all locations (Figure 5). In the C-S and C-C-S rotations, year-to-year variability was generally smaller compared to that for the continuous corn (C-C). For example, the coefficient of variation (CV) for the C-C, C-C-S and C-S rotations in central Iowa (near Ames) was 37, 17, and 19%, respectively, with similar trends in CV at the southern locations of Armstrong and Crawfordsville. On the other hand, yearly variability of corn yield in the northern locations

(Kanawha, Nashua and Sutherland) was approximately similar.

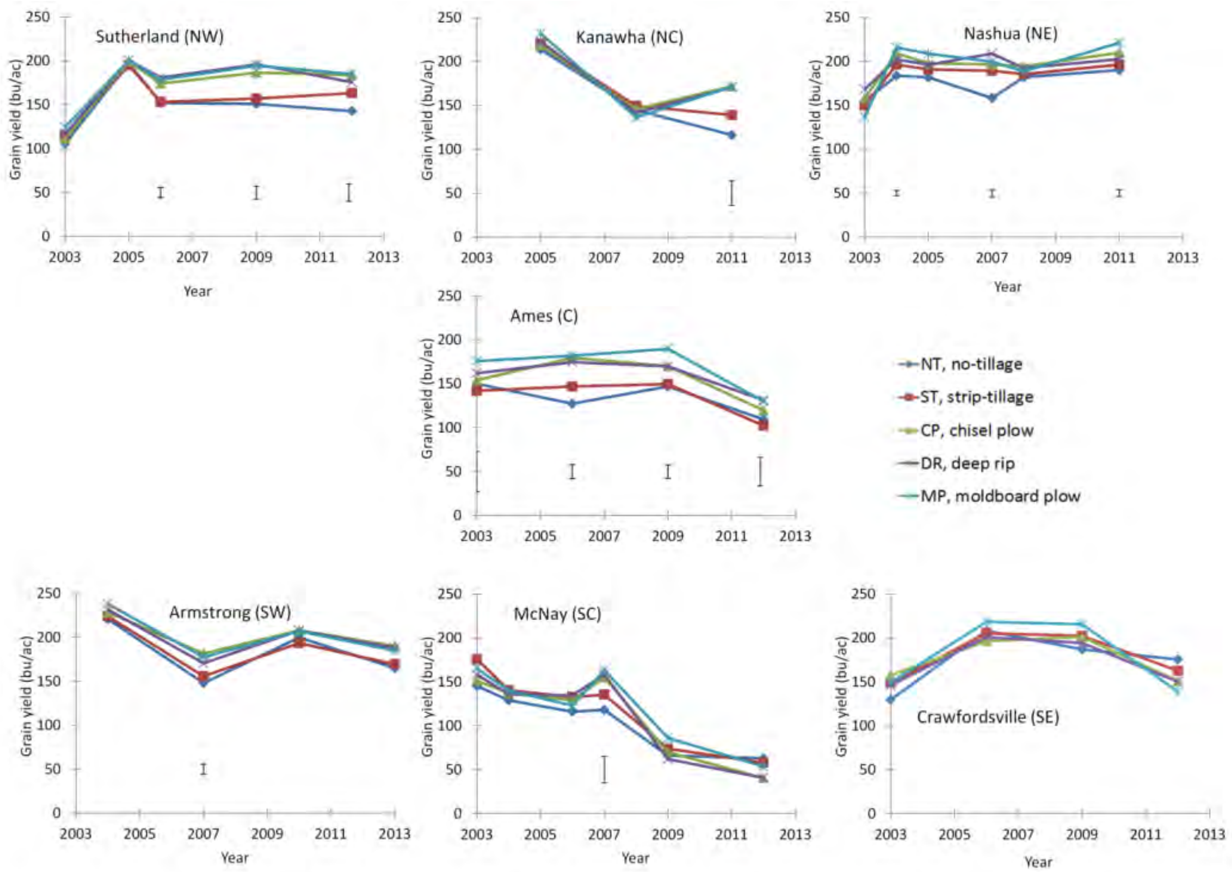

Figure 5. Effect of five tillage systems on temporal variation in corn yield in a corn-corn-soybean (C-C-S) across seven locations in Iowa. Vertical bars where visible, indicate the two times tandard errors of difference between tillage systems at P<0.05. CV is the coefficient of variation.

In the continuous corn (C-C) system (Figure 6), the highest CV (37%) was observed in central Iowa (near Ames) compared to 12% in Sutherland in northwestern Iowa. The difference in variability for corn yields between both locations was the result of delayed planting (10 days late) due to wet spring conditions in the last two years (2012 and 2013) of the study. The drought conditions of 2012 also affected corn yields and the difference in the variability. In 2013, tillage had a significant effect on corn yield, where the conventional tillage (CP, DR and MP) system significantly (P<0.01) increased corn yield in Ames location. Corn yield penalty in the C-C system can be related to the cumulative effect of growing the same crop for many years as documented by Gentry et al., 2013, where the number of years of continuing the same crop is the most important factor in affecting yield response. This finding of cumulative effect of continuous corn on the yield is consistent with the findings of this study.

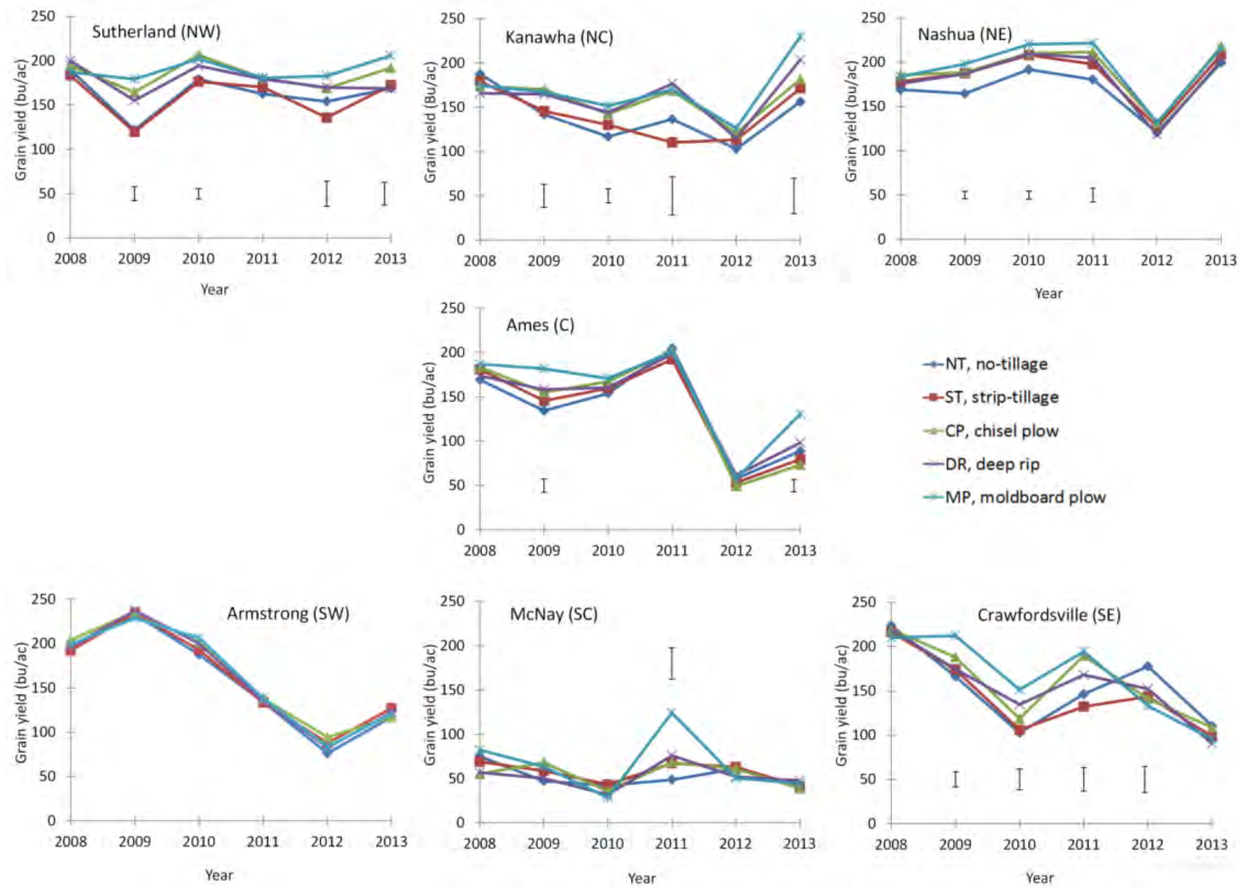

Figure 6. Effect of five tillage systems on temporal variation in corn yield in a continuous corn (C-C) system across seven locations in Iowa. Vertical bars where visible, indicate the two times standard errors of difference between tillage systems at P<0.05. CV is the coefficient of variation.

On average, the variability in corn yield across locations for three rotations (C-C, C-C-S and C-S) was 37, 25, and 23%, respectively, which are consistent with findings in Iowa (Karlen, et al., 2013) and in Pennsylvania (Grover et al., 2009). Overall, the year-to-year variability in corn yield across locations, tillage systems and rotations in this study was 28%. Despite the challenging explanation of annual variability in corn yield, the analysis of temporal variability in this study was helpful in identifying crop rotations associated with high and stable yields and /or production risks, which provide important guidelines for management recommendations for farmers.

Effects of tillage and crop rotation on input cost and economic return for corn

The effects of interaction between tillage and location at different location due to soil types and drainage differences on input cost (P=0.01) and economic return for corn (P=0.02) were significant in the C-S rotation. However, these effects were no significant on input costs and economic returns in the C-C-S and C-C rotations (Table 2 and Figure 7). As expected, input costs for the conventional tillage systems (CP, DR, and MP) were 7.5% and 5.7% higher than those for the NT and ST systems, respectively across all locations and for all crop rotations (Table 2).

In the C-S rotation, there was variability in economic returns between locations ($153/acre to $ 485/acre) where the economic return for the NT system was significantly lower than that for conventional tillage (CP, DR and MP) and the ST systems except for the northwest (NW), southwest, and southeast locations (Table

2). Besides the economic returns at the south central (McNay) location that was consistently low due to poorer soil conditions, the economic returns at six locations for all tillage systems in the C-C-S rotation, except for central Iowa (Ames), were not significantly different. At the Ames location, NT had the lowest economic return compared to other tillage systems (Table 2).

In the C-C rotation, economic returns for all tillage systems were also not significantly different except for the NW location, where economic returns for both the NT and ST systems were significantly lower than those from the conventional tillage systems. The average economic returns from the C-S, C-C-S and C-C rotations were $388, $333 and $227, respectively.

The effect of rotation on corn yield was in the following order: C-S > C-C-S > C-C where the corn yield and economic return of the C-S rotation were consistently superior (P=0.05) to C-C-S and C-C by 5 and 11% and 11 and 31%, respectively at the northern locations (Sutherland, Kanawha and Nashua). Generally, there was significant reduction in corn yield in the continuous corn system than the C-S system across all location in the range of 11-28%.

Table 2. Effects of five tillage systems and crop rotations on average input cost and economic return for corn over 10 years in Iowa. Significant interactions between tillage and rotation were found in the C-S rotation only ($P < 0.05$).

		§NT	ST	CP	DR	MP		NT	ST	CP	DR	MP	
Rotation†	Location‡	Input cost $/acre					Average	Economic return $/acre					Average
C-S	Sutherland	393.93a	400.81b	425.91c	425.91c	425.91c	414.49	397.98a	393.93a	423.08a	404.05a	423.48a	408.50
	Kanawha	385.43a	394.74b	419.84c	418.22c	420.65c	407.77	394.74a	421.05b	469.23b	451.01b	479.35b	443.08
	Nashua	392.31a	401.62a	425.91b	425.51b	424.70b	414.01	448.99a	497.17b	500.81b	498.79b	480.57b	485.26
	Ames	390.69a	399.19b	425.51c	425.10c	425.91c	413.28	295.55a	324.70a	373.28b	366.80b	385.43b	349.15
	Armstrong	395.55a	404.05a	427.53b	427.53b	427.53b	416.44	447.77a	470.45a	468.83a	463.97a	453.85a	460.97
	McNay	376.92a	384.62b	410.93c	410.53c	411.34c	398.87	119.03a	132.39ab	173.28b	163.16b	178.54b	153.28
	Crawfordsville	395.95a	402.83b	426.32c	426.32c	426.72c	415.63	422.27a	415.38a	417.41a	402.43a	425.10a	416.52
C-C-S	Sutherland	407.69	415.79	441.70	441.70	441.70	429.72	278.54	301.21	340.49	353.85	365.18	327.85
	Kanawha	408.91	417.81	442.91	442.91	443.32	431.17	304.86	346.56	363.56	362.75	369.23	349.39
	Nashua	412.55	421.05	446.15	446.15	446.15	434.41	380.57	414.57	434.82	436.03	441.70	421.54
	Ames	404.05	411.74	439.27	440.08	441.70	427.37	201.62	216.60	293.12	302.02	343.32	271.34
	Armstrong	414.17	421.46	447.77	446.96	447.37	435.55	414.57	418.22	467.61	455.06	465.59	444.21
	McNay	398.79	408.10	429.96	430.36	431.58	419.78	88.66	139.27	91.90	97.17	127.13	108.83
	Crawfordsville	412.96	421.86	444.53	443.72	446.56	433.93	389.07	428.34	402.83	383.00	443.72	409.39
	Means	408.44a	416.83b	441.76c	441.70c	442.63c		293.98a	323.54ab	342.05b	341.41b	365.12b	
C-C	Sutherland	430.36	436.44	464.37	463.16	465.18	451.91	311.74	291.90	376.52	347.77	399.19	345.43
	Kanawha	425.51	432.39	459.11	459.51	461.13	447.53	208.50	209.31	269.23	280.57	316.19	256.76
	Nashua	416.60	425.91	453.44	448.58	451.01	439.11	361.13	418.22	414.57	384.21	440.89	403.81
	Ames	424.70	431.17	454.66	455.47	458.30	444.86	189.88	184.62	175.71	190.28	246.56	197.41
	Armstrong	429.15	436.84	460.32	459.92	459.92	449.23	285.83	298.38	292.31	279.76	282.19	287.69
	McNay	407.69	415.38	437.65	437.65	440.08	427.69	-168.83	-155.47	-188.66	-197.98	-140.89	-170.36
	Crawfordsville	407.29	414.17	438.46	437.65	439.27	427.37	289.07	231.98	270.45	253.04	295.95	268.10
	Means	420.19a	427.47a	452.57b	451.71b	453.56b		211.05a	211.28a	230.02a	219.66a	262.87b	

† Cropping system C-C; continuous corn, C-C-S; corn-corn-soybean; C-S, corn-soybean.

‡ Location Ames (Central Iowa); Crawfordsville (Southeast Iowa); Kanawha (north central Iowa); Armstrong (Southwest Iowa); McNay (south central Iowa); Nashua (Northeast Iowa); Sutherland (Northwest Iowa).

§ Tillage system: NT (no-tillage); ST (strip-tillage); CP (chisel plow); DR (deep rip); MP (moldboard plow).
Different lowercase letters within a row indicate statistically significant differences among tillage systems ($p<0.05$).

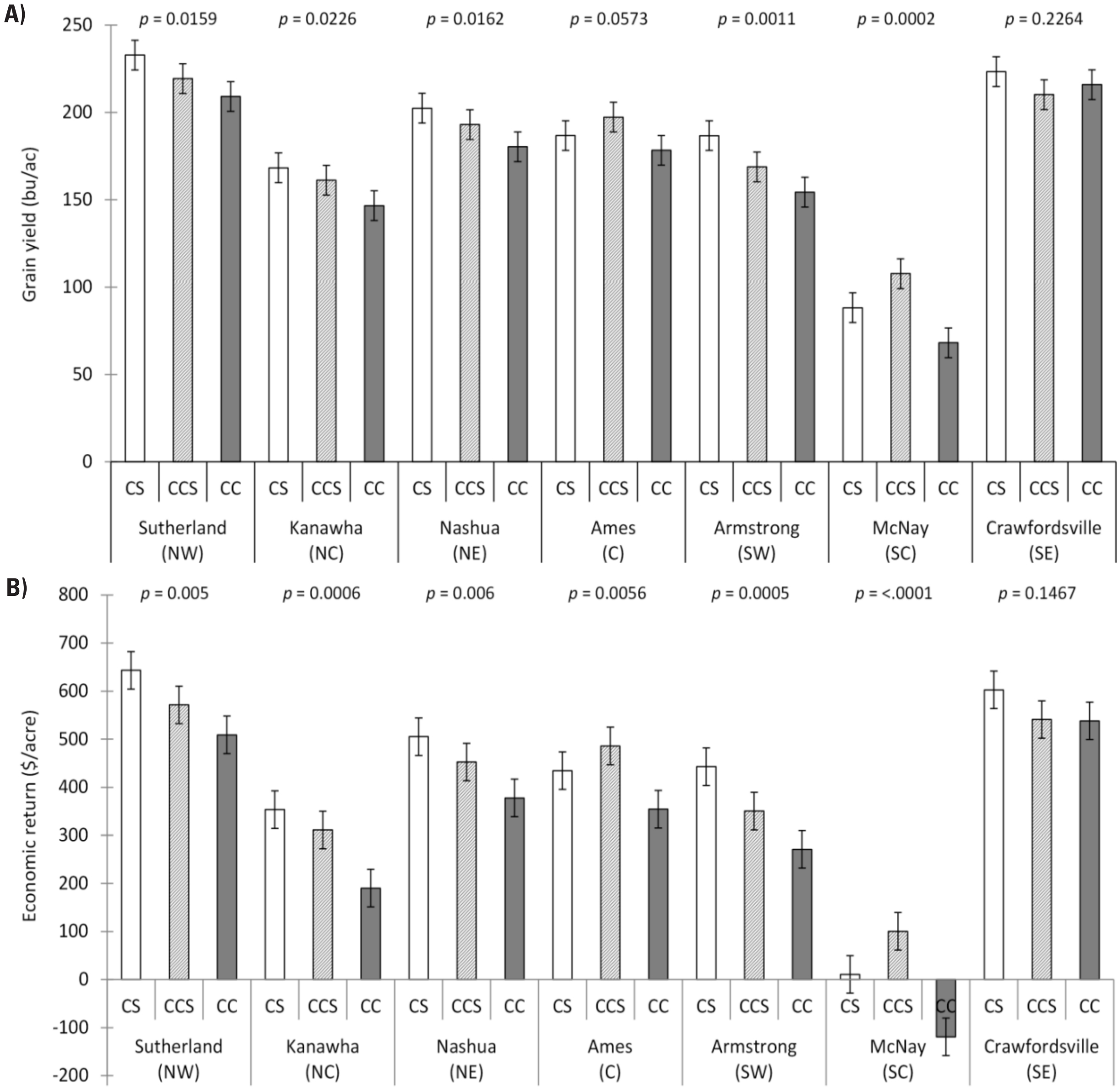

Figure 7. Regional corn yield (A) and economic return (B) as affected by crop rotation at seven locations in Iowa. P-values calculated for each location's crop rotation comparison is at $P<0.05$. Vertical bars indicate the standard error of the mean values.

Soybean results: Temporal and spatial variability in soybean yield

Soybean yield varied with tillage systems across locations and years in the range of 22 bu/acre to 74 bu/acre without any detectable trend in yields over the 10-year period of the study (2003-2013). Although soybean yield at Nashua in northeast Iowa was the lowest in 2003, soybean yields at McNay in south central Iowa were consistently low in the C-S rotation (Figure 8). At the Armstrong and Sutherland locations, soybean yields reached 74 bu/acre in 2005 and 2009 in the C-S rotation but lower than 74 bu/acre in all years at other locations. The yearly variability in soybean yield across locations was 20% in the C-S rotation and 22% in the C-C-S rotation (Figure 8 and Figure 9). With both rotations, the lowest annual soybean yield variability (16%) was observed at Crawfordsville in southeast Iowa and the highest variability (26%) in central Iowa, Ames. Within each rotation there were significant interactions among years, locations, and tillage systems. The effect of tillage on soybean yield was significant in 12 out of 49 yr-locations with the C-S rotation and 9 out of 32 yr-locations with the C-C-S rotation. When there was a significant difference in soybean yields, yields with conventional tillage systems (CP, DR, and MP) were higher than yields with NT and ST, with the exception of soybean yields in the C-S rotation at McNay, where yield with NT was the highest among other tillage systems. The ratio between maximum and average soybean yield in this study is an indication of soybean yield gap, which varied from 17 to 30% across locations. At the McNay location in south central Iowa, the 2004 high yielding year for soybean (Figure 8) was associated with less precipitation in May, cooler summer temperatures and higher precipitation in August. Similarly, the high-yielding years of 2005 and 2009 at the Crawfordsville location in southeast Iowa was also the result of cooler summer temperatures and greater precipitation in August. This finding shows that soybean yields were maximized in some years because of favorable weather conditions regarding temperature and precipitation distribution.

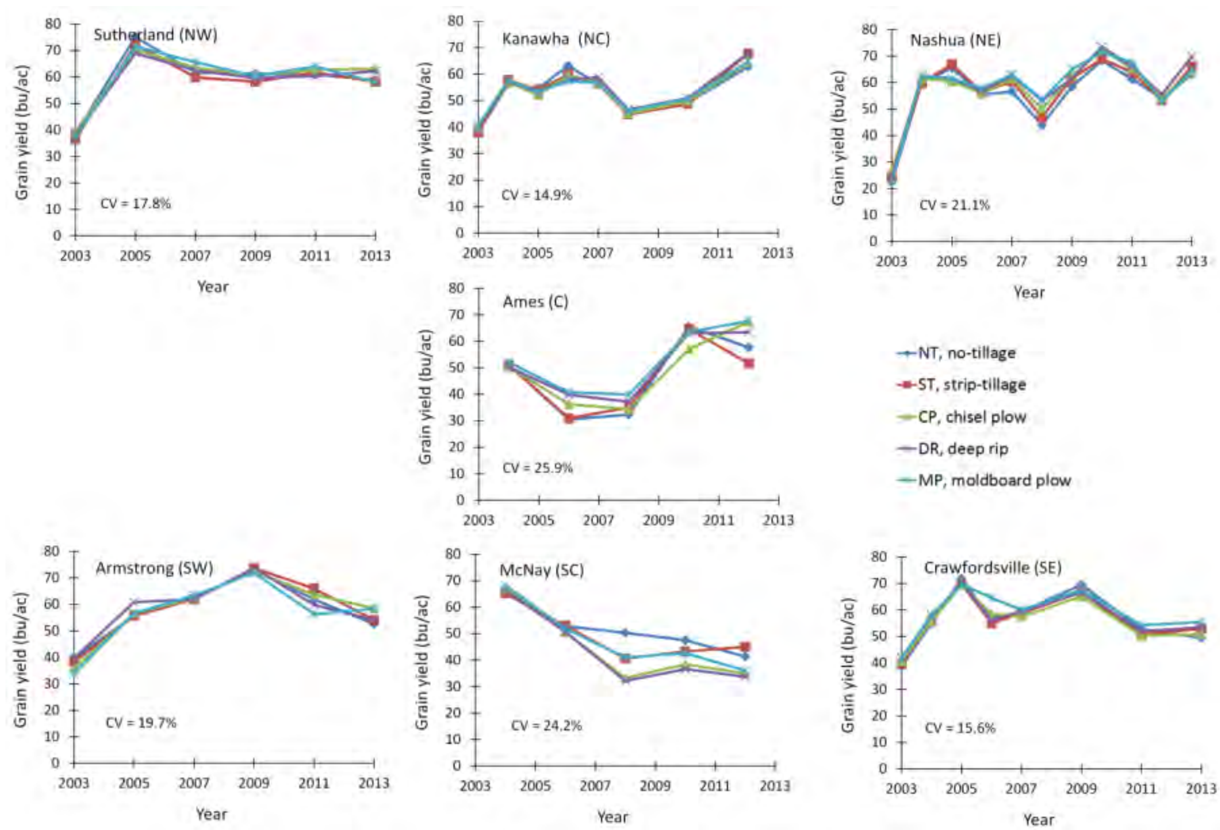

Figure 8. Temporal variation in soybean yield in a corn–soybean (C-S) rotation as affected by five tillage systems at seven locations across Iowa. Vertical bars (where visible) indicate differences among the tillage systems at $p < 0.05$. Average CV values are also shown for each location.

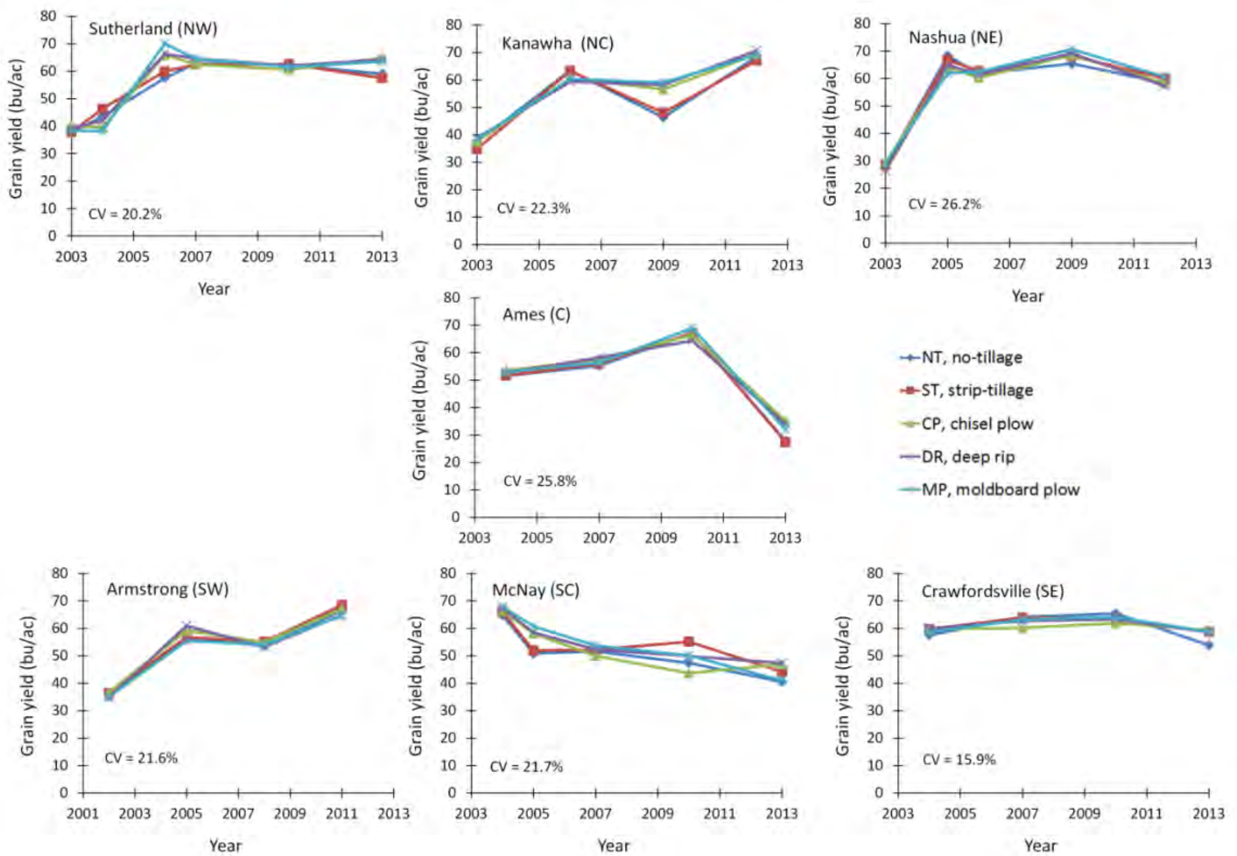

Figure 9. Temporal variation in soybean yield after 2 years of corn in a corn–corn–soybean (C-C-S) rotation as affected by five tillage systems in seven locations across Iowa. Vertical bars (where visible) indicate a statistically significant difference among the tillage systems at p < 0.05. Average CV values are also shown for each location.

Effects of tillage and crop rotation on soybean yield, input cost and economic return

The regional soybean yield response to tillage systems was different for both rotations with significant interactions (P<0.001) between tillage and location for the C-S rotation but not the C-C-S rotation (P=0.78). However, the effect of tillage on regional soybean yield was significant (P=0.023) in the C-C-S rotation, but no effect for location (P=0.80). At four locations (Sutherland, Kanawha, Armstrong and Crawfordsville), soybean yields with conventional tillage (CP, DR, and MP) were significantly different from the yields with NT or ST. At McNay, soybean yield in the C-S rotation with NT was 11% higher than the yields with MP and DR (Table 3). On the contrary, soybean yields with NT at Nashua and in Ames were significantly lower (5% and 9%, respectively) than the yields with MP and DR. Across all locations, soybean yields with conventional tillage systems (CP, DR and MP) in the C-C-S rotation, were 4% greater than those for NT (Table 3).

The input cost for soybean production excluded land rent and crop insurance, which are fixed costs for all locations. The input cost for NT soybean production was lower than that for conventional tillage systems in both rotations (Table 3). Significant interactions (P=0.001) were found between tillage systems and locations for input cost and economic return for soybean production in the C-S rotation. In the C-C-S rotation, tillage systems significantly affected input cost (P=0.001), but not economic return (P=0.997).

In the C-S rotation, economic returns at Ames, McNay and Nashua were different among tillage systems. In Ames and at Nashua, the conventional tillage systems (CP, DR and MP) resulted in 13 and 5% increase in economic return, respectively compared to NT and ST. At McNay, the NT and ST systems resulted in 17% increase in economic return than the conventional tillage systems. In the C-C-S rotation, tillage did not affect economic return (Table 3).

Generally, soybean yield in the C-C-S rotation across all locations with conventional tillage (CP, DR and MP) was 4% greater than the yield with NT. However, soybean yield with NT in the C-S rotation at the McNay location was 11% higher than the yields with MP and DR.

Input cost with conservation tillage (NT and ST) for soybean production was lower with greater economic return than conventional tillage (CP, DR and MP) in both rotations systems (C-S and C-C-S). Economic return for soybean with NT and ST resulted in 17% increase compared with conventional tillage. However, economic return with conventional tillage (CP, DR and MP) in the C-S rotation in central Iowa (Ames) and northeast Iowa (Nashua) was 13% and 5% and 4% and 0.4% greater than that with NT and ST, respectively. In the C-C-S rotation, tillage did not affect economic return.

Table 3. Effects of five tillage systems and crop rotations on average yield, input cost and economic return for soybean over 10 years in Iowa.

	Corn-soybean rotation						Corn-corn-soybean rotation					
Location[‡]	**[§]NT**	**ST**	**CP**	**DR**	**MP**	**Average**	**[§]NT**	**ST**	**CP**	**DR**	**MP**	**Average**
	Grain yield bu/acre											
Sutherland	59.83	58.19	60.43	59.09	59.98	59.50	55.66	56.41	57.60	58.34	58.05	57.21
Kanawha	54.32	54.47	54.18	55.07	54.47	54.50	55.07	54.03	57.00	57.90	57.75	56.35
Nashua	55.51	57.15	57.90	58.94	58.64	57.63	56.26	57.15	56.26	55.81	57.15	56.53
Ames	46.29	45.69	48.82	50.75	52.69	48.85	50.31	50.45	52.98	52.24	52.54	51.70
Armstrong	58.05	58.79	58.64	58.79	57.15	58.28	52.09	53.43	53.73	52.69	51.50	52.69
McNay	51.05	48.97	44.35	43.46	47.48	47.06	50.16	52.98	52.09	54.18	53.88	52.66
Crawfordsville	56.56	56.11	55.81	57.00	58.79	56.85	60.13	61.32	60.28	61.02	61.17	60.78
Mean	—	—	—	—	—	—	54.24a	55.11ab	55.71bc	56.03bc	56.00bc	
	Input cost $/acre											
Sutherland	188.26	193.93	208.10	207.69	207.69	201.13	187.85	193.52	207.29	207.69	207.69	200.81
Kanawha	187.45	193.12	206.88	207.29	207.29	200.40	187.85	193.12	207.29	207.29	207.29	200.57
Nashua	187.85	193.52	207.69	207.69	207.69	200.89	187.85	193.52	207.29	207.29	207.69	200.73
Ames	186.64	191.90	206.48	206.48	206.88	199.68	187.04	192.71	206.88	206.48	206.88	200.00
Armstrong	188.26	193.93	207.69	207.69	207.29	200.97	187.45	193.12	206.88	206.88	206.48	200.16
McNay	187.04	192.71	205.67	206.07	206.07	199.51	187.04	193.12	206.88	206.88	206.88	200.16
Crawfordsville	187.85	193.52	207.29	207.29	207.69	200.73	188.66	194.33	207.69	207.69	208.10	201.30
Means	—	—	—	—	—		187.68a	193.35b	207.17c	207.17c	207.29c	
	Economic return											
Sutherland	578.95	553.85	566.40	549.80	559.92	561.78	526.72	530.36	530.36	548.58	536.03	534.41
Kanawha	508.10	506.07	486.23	497.98	491.50	497.98	516.60	471.66	522.27	532.79	530.77	514.82
Nashua	522.67	539.68	533.60	547.77	543.72	537.49	531.98	540.49	512.55	508.50	525.10	523.72
Ames	406.88	395.14	418.62	444.53	467.61	426.56	458.30	455.47	472.87	462.75	465.59	463.00
Armstrong	555.47	559.92	544.53	546.15	525.91	546.40	480.57	492.71	480.97	468.42	453.04	475.14
McNay	466.40	436.03	362.75	351.01	402.43	403.72	455.87	487.45	461.13	487.45	482.59	474.90
Crawfordsville	536.44	525.91	508.50	523.89	545.75	528.10	583.00	593.52	564.78	574.90	575.71	578.38
Means	—	—	—	—	—		507.58a	510.24a	506.42a	511.91a	509.83a	

‡ Location: Ames (central Iowa); Armstrong (south west Iowa); Crawfordsville (southeast Iowa); Kanawha (north central Iowa); McNay (south central Iowa); Nashua (northeast Iowa).

§ Tillage system: NT (no-tillage); ST (strip-tillage); CP (chisel plow); DR (deep rip); MP (moldboard plow). Average values across the experimental years. Rotation: C-C-S (soybean after second year corn); C-S (corn-soybean). Different lowercase letters within a row indicate statistically significant differences among tillage systems ($p<0.05$). Land rental cost was not included in calculating economic return, where it was the same across locations.

Effect of rotation on soybean yield and economic return

Soybean yield and economic return after two years of corn (C-C-S) was 5-9% and 5-11%, respectively, higher than soybean yield and economic after one year of corn (C-S) in five out of the seven locations (Figure 10). However, the magnitude of rotation effect on soybean yield was variable across the seven locations because of the different soil types and weather conditions. The location with the greatest response of soybean yield to rotation was Crawfordsville (15%) followed by Armstrong (14%) and McNay (13%). The interaction effect of tillage x location x rotation and that of rotation x tillage on soybean yield and economic return were not significant, (*P*=0.30) and (*P*=0.58), respectively. However, the interaction effect of rotation x location on soybean yield and economic return was highly significant (*P*=0.005). Overall, soybean yield and economic return in the C-C-S rotation at five out of seven locations in Iowa were 5-9% and 5-11% greater, respectively, than the yield and economic return in the C-S rotation.

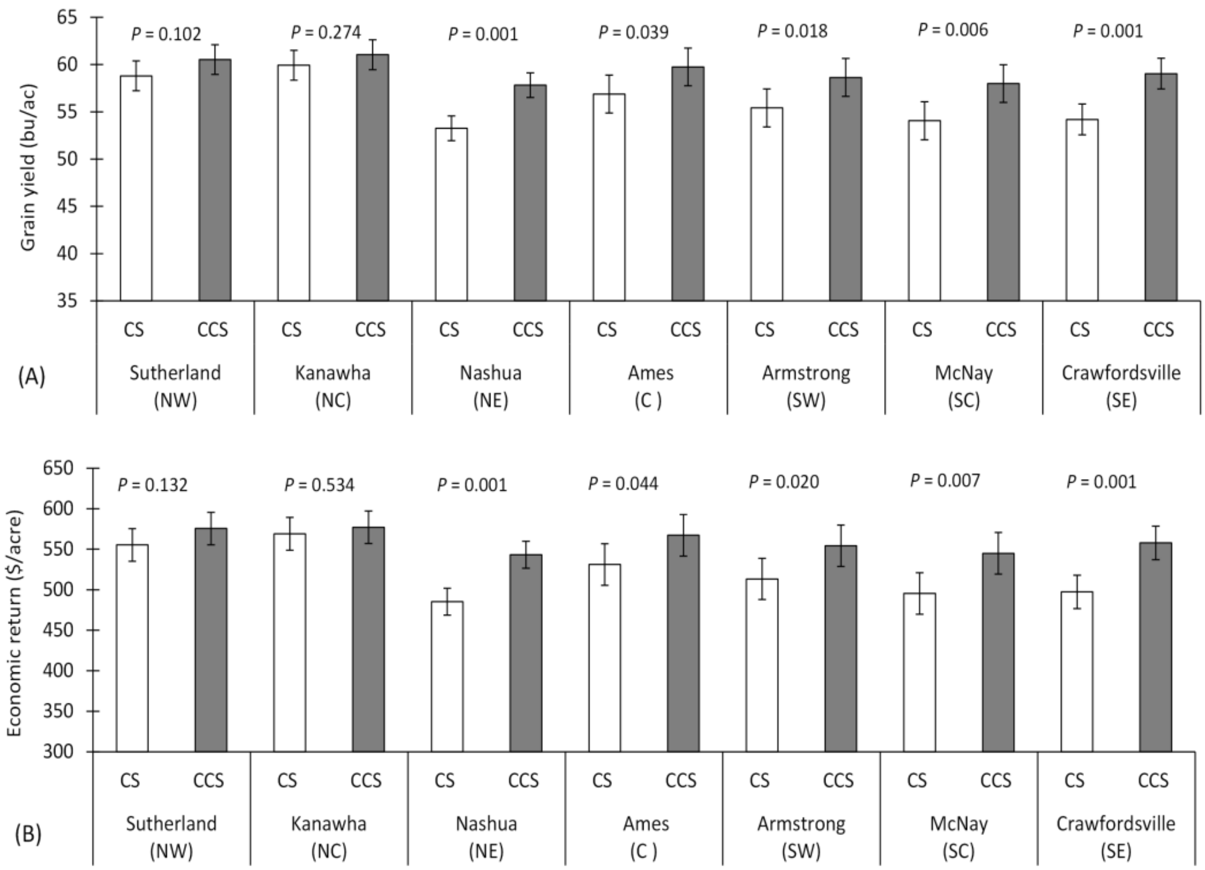

Figure 10. (A) Soybean yield and (B) Economic return as affected by crop rotation across seven Iowa locations. Rotations: corn–soybean (C-S) and corn–corn–soybean (C-C-S); locations: northwest (NW), north-central (NC), northeast (NE), central (C), southwest (SW), southcentral (SC), and southeast (SE). Land rental cost was not included in calculating the economic returns, as this was the same across locations.

Cropping system economic return

The analysis of economic returns for the cropping systems in this study that include continuous corn (C-C), corn-soybean rotation (C-S) and two consecutive years of corn followed by soybean (C-C-S) for all locations presented in Figure 11. The analysis of variance of the cropping systems did not show significant interactions (*P*=0.110) between location x year x cropping system for economic return. However, cropping system, location and year individually showed significant effects (*P*=0.0152), (*P*=0.040) and (*P*=0.037), on economic return, respectively, where cropping system showed the strongest effect. Overall across all the locations, the average economic return per acre for the C-S rotation ($388) was 14% higher than that with the C-C-S rotation ($333) and 41% higher than that the C-C rotation ($227).

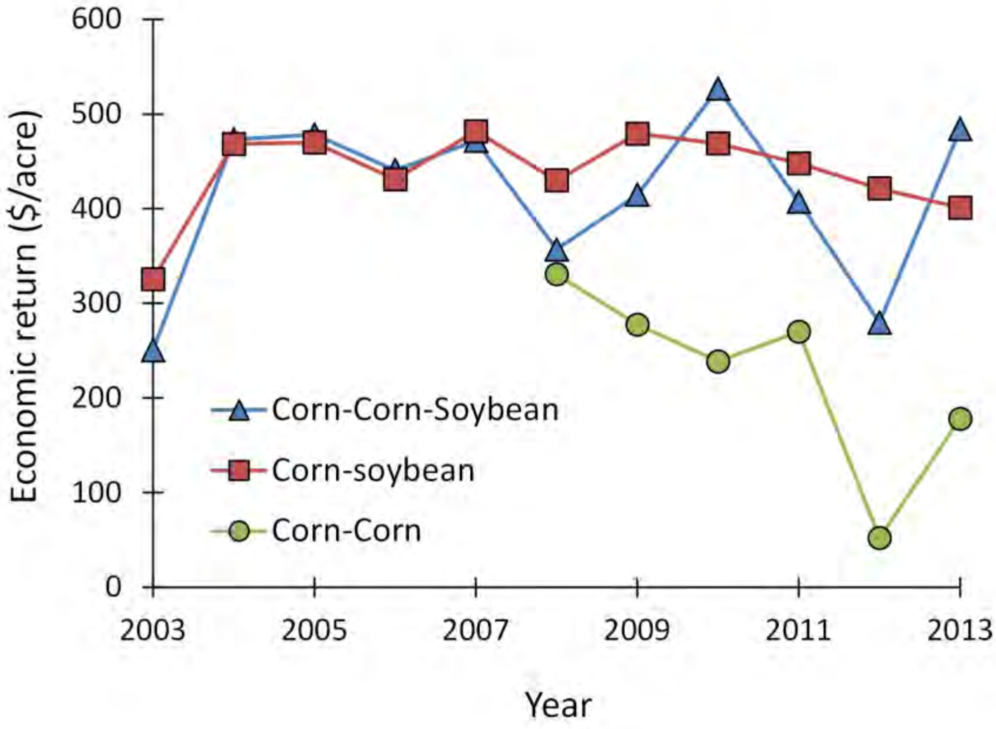

Figure 11. Average effect of crop rotation on economic return across several locations and five tillage systems in Iowa. Land rental cost was not included in calculating economic return, as this was the same across locations.

Conclusions

The results show specific regional soil and weather conditions effects on corn yield and economic return with different tillage systems and crop rotations. Corn yield response to different tillage systems within each crop rotation was similar with a few exceptions, where corn yield with NT was significantly lower than corn yield with conventional tillage systems, especially in the northern locations (poorly-drained soils) of Iowa. Our results confirm the general trend in corn yield decline for continuous corn (C–C) compared with corn yield in corn-soybean (C–S) rotation by 11-28%. The yield and economic return decline with the continuous corn (C–C) system is location specific, influenced by location latitude and soil formation characteristics. The input cost for corn production with conventional tillage systems (CP, DR, and MP) was greater than NT and ST by 7.5 and 5.7%, respectively. The results of this study suggest that corn yield and economic return with NT and ST at locations with well-drained soils, can be as competitive as those with conventional tillage systems. The yield decline in the C–C system is highly related to rotation effect regardless of tillage system or location in the state. The effect of cropping system on economic return generally showed greater stability and profitability with C-S rotation followed by the C-C-S rotation. The average economic return per acre for C-S rotation ($388) was 14% higher than the C-C-S rotation ($333) and 41% higher than the C-C rotation ($227), suggesting the long-term stability of yield and economic return of cereal-legume rotation over a mono-cropping system.

Soybean response to crop rotation is highly influenced by region-specific conditions (i.e., soil type, weather variability, etc.). Tillage systems in the majority of locations had no significant effects on soybean yield and economic returns, but crop rotation had significant effects on soybean yield and economic returns. Soybean yields across locations in southern Iowa with well-drained soils and warmer temperatures were greater than yields in the central and northern locations of the state with cooler temperatures and poorly to moderately well-drained soils. Significant differences in yield and economic return were observed at the northern and southern locations, with 15 to 21% yield variability across the northern locations and 16 to 24% across the southern locations. In the southern part of the state with frequent drought events, conservation tillage (NT and ST) practices showed an advantage over conventional tillage systems (CP, DR, and MP). Soybean yield and economic return with the C-C-S rotation showed an advantage over the C-S rotation. On average, NT had a lower input cost ($187/acre) and a greater economic return ($509/acre) than conventional tillage ($207/acre and $502/acre, respectively).

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