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Stepwise time response of corn yield and economic return to no tillage

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Abstract

The adoption of no tillage (NT) in crop production has been encouraged primarily due to its more significant benefits to the environment compared with other conservation tillage systems. There are nevertheless concerns about NT corn (*Zea mays* L.) performance from both short- and long-term perspectives. This study was conducted near Burlington, Nashua, Newell, Sutherland, and Crawfordsville in Iowa from 1978 through 2001 to evaluate corn production in 4- to 5-year phases under long-term NT management. Field experiments were conducted using a complete randomized block, or split-plot design. Seven tillage systems including NT, moldboard plow (MP), ridge tillage (RT), chisel plow (CP), reduced tillage (RDT), field cultivation (FC), and tillage-plant (TP) were evaluated in terms of corn yield and economic return. Differences between NT and other tillage systems in either corn yield or economic return did not change with the 4- to 5-year phases within the entire study period. The competitiveness of NT over MP, RT, CP, or other tillage systems in the early years (first 4–5 years) since tillage adoption, was as strong as that after 8–10 years. This finding is encouraging to those corn producers who are reluctant to use NT, because of their concern about the poor performance of NT corn during the early years. Yield differences between NT and other tillage systems in each 4- to 5-year phase, or averaged over the entire study period, were mostly within 5% in a corn–soybean (*Glycine max* (L.) Merr.) rotation. No tillage generally had equal or greater economic return than other tillage systems in each 4- to 5-year phase and over the entire study period. The yield and economic return benefits of a corn–soybean rotation relative to continuous corn remained generally the same over time under long-term NT management. Therefore, the adoption of a NT system can be accomplished without lowering the economic return from both short- and long-term perspectives.

Keywords: Corn; Yield; Economic return; Stepwise time response; No tillage; Moldboard plow; Chisel plow; Ridge tillage

1. Introduction

Conservation tillage systems offer pronounced advantages over moldboard plow (MP) of conserving soil and water, sustaining soil productivity, reducing labor and energy requirements, and possibly, more timely planting in years when wet soils delay conventional tillage operations (Unger and McCalla, 1980; Conservation Tillage Information Center, 1983). Because no tillage (NT) results in less soil disturbance and greater residue coverage on the soil surface than other conservation tillage systems, it offers more significant benefits to the environment.

No tillage production has increased steadily in the United States during the last decade. In 2002, NT was used in nearly 20% of all cropland area (Conservation

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Technology Information Center, 2003), which almost doubled that in 1992. However, only 18% of corn was under NT management in 2002, whereas 33% of soybean was under NT. Therefore, even with the cited advantages, some notable difficulties remain that have hampered the adoption of NT practices for corn production. One of the main concerns corn producers have is the perception that NT will lower corn yield and economic return, particularly during the first few years of adoption.

Research has shown that corn yield response to NT depends mainly upon previous crop and soil drainage characteristics (Dick and van Doren, 1985; Griffith et al., 1988; Guy and Oplinger, 1989). In general, well-drained soils, crop rotation, and warmer climates make NT corn yield more competitive than under poorly drained soils, continuous cropping, and cooler climates (Griffith and Wollenhaupt, 1994). Studies in Indiana (Griffith et al., 1973) showed that NT produced greater yield on well-drained sandy loam and silt loam soils, but less yield on a dark and poorly drained soil, than did MP for 7-year continuous corn. Hesterman et al. (1988) reported in Michigan that continuous corn yield of NT and MP systems did not differ on a somewhat poorly drained loam and a well-drained sandy loam. Brown et al. (1989) reported in Iowa that NT corn yield was less than MP, disking, and field cultivation (FC) on both a poorly drained soil and a somewhat poorly drained soil in a corn–soybean rotation. McIsaac et al. (1990) found in a 9-year tillage study on a poorly drained soil in Illinois that NT corn yield was less than with other tillage systems. No tillage in Minnesota reduced continuous corn yield by 15% compared with MP on a poorly drained soil, but by only 5% on a moderately well-drained soil (Moncrief et al., 1990, 1991).

In general, continuous corn yields have been less under NT than MP systems on silt loam or finer textured soils (Dick and van Doren, 1985; Griffith et al., 1988; Meese et al., 1991; West et al., 1996). Less-than-desirable or inconsistent corn yield performance under NT management has been related to several factors such as delayed crop growth and development and increased difficulties with pest control and soil management. A yield reduction due to NT can often be offset, at least partially, by rotating corn with other crops (Dick and van Doren, 1985; Griffith et al., 1988; Chase and Duffy, 1991; Dick et al., 1991; West et al., 1996). Meese et al. (1991) reported a yield decrease of about 10% for continuous corn in NT compared with MP, whereas the yield under these two tillage systems was generally similar for corn in a corn–soybean rotation. In addition, reducing residue quantity on the soil surface (Kaspar et al., 1990) or in tilling seed zones (Vyn and Raimbault, 1992) may improve the in-row seedbed characteristics of NT systems, and thus result in NT corn yield similar to that obtained with MP.

Acceptance of NT for corn probably depends more on its profitability, rather than grain yield alone. Profitability for corn depends on the relative magnitude of revenue (grain yield × price for grain) and total production cost. In general, NT has lower costs in labor, fuel, and machinery inputs, but greater costs in pesticides and intensive management to maintain or increase yield compared with MP. Studies have shown that economic return for NT relative to conventional or other conservation tillage systems varies with many factors such as management practices, crop rotation, and labor costs. Chase and Duffy (1991) in Iowa found that the economic return for corn under NT was similar to that under MP, ridge tillage (RT), or chisel plow (CP) in a corn–soybean rotation when the hourly labor cost was $ 10 or greater. Duffy and Hanthorn (1984) compared the economic return of corn under three tillage systems (NT, reduced tillage (RDT), and MP) from randomly sampled fields mainly from the Midwest (Iowa, Illinois, Indiana, Minnesota, and Ohio), and found that there was no significant difference among tillage systems. Doster et al. (1983) reported that NT ranked second, next to RT, among six tillage systems in economic return for corn on light and well-drained soils with 3% or greater slope, in both continuous corn and corn–soybean rotations on a hypothetical 300 ha farm in Indiana.

Information on the effect of time since tillage adoption on corn yield and economic return is limited and the results are variable. Dick et al. (1991) reported in Ohio that after 18 years, the negative impact of NT on corn yield on a poorly drained soil was greatly decreased compared with that found in previous years, whereas the corn yield advantage associated with NT relative to MP on a well-drained soil became even more pronounced. However, Chase and Duffy (1991) reported that there was no significant improvement in the performance of either corn yield or economic return with NT relative to those under other tillage systems with time since tillage adoption in a 10-year Iowa tillage study.

Response of corn yield and economic return to NT management has been evaluated either over the entire study period or for an individual year in previous publications. However, little is known about the stepwise time response of corn yield and economic return to NT compared with other tillage systems. The primary objectives of this study were to (1) evaluate the stepwise time response of corn yield and economic return to NT relative to MP, RT, CP, and other tillage systems in several long-term studies across Iowa; and (2) assess corn–soybean rotation effects on NT corn performance relative to other tillage systems in successive phases of long-term studies.

2. Materials and methods

2.1. Site description

This study was conducted at Burlington (40.8°N, 91.1°W), Nashua (43.0°N, 92.5°W), Newell (42.6°N, 95.0°W), Sutherland (43.0°N, 95.5°W), and Crawfordsville (41.2°N, 91.5°W) in Iowa with different experimental designs and lengths of investigation at each location. Main soil information for each location is presented in Table 1. The Burlington experiment was conducted from 1980 to 1992 on a poorly drained and moderately slowly permeable soil, formed on loess, with slope from 0 to 1%. The experiment at Nashua was at the Iowa Experiment Station Research Farm from 1978 through 1992 on a moderately well-drained and moderately permeable soil, formed on friable loamy erosion sediments overlying firm loamy glacial till, with slope from 2 to 5%. The experiment at Newell was conducted from 1980 to 1986 on a well-drained soil, formed on loamy, calcareous glacial till or sediment derived from glacial till, with slope from 2 to 5%. The Sutherland experiment was at the Iowa Northwest Research Farm from 1994 through 2001 on a well-drained and moderately permeable soil, formed on loess, with slope from 2 to 5%. The experiment at Crawfordsville was conducted from 1990 to 2001 on Kalona and Nira soils. The Kalona soil was poorly drained and moderately slowly permeable, formed on loess, with slope from 0 to 2%. The Nira soil was moderately well drained and moderately permeable, formed on deoxidized loess, with slope from 5 to 9%. The native vegetation at all locations was predominantly prairie grasses.

2.2. Experimental design and implementation

A randomized complete block design with three to six replicates (varying with locations) was used at Burlington, Nashua, Newell, and Crawfordsville. Tillage systems were the treatments. At Burlington, NT, RDT, and MP systems were evaluated in a corn–soybean rotation each season. At Nashua, NT, RT, CP, and MP systems were tested in two crop rotations of continuous corn and corn–soybean each year. Five tillage systems, including NT, CP, MP, FC, and tillage-plant (TP) were evaluated in a corn–soybean rotation at Newell. The Crawfordsville site had NT, RT/alternative tillage (AL), and CP systems that were assessed in both continuous corn and crop–soybean rotations for 13 years. Alternative tillage consisted of NT drilled soybean and FC ahead of corn in a corn–soybean rotation. In continuous corn, fall CP was followed with direct planting in the spring. The RT treatment at this location was changed to AL after 5-year implementation in both crop rotations.

Table 1
Major soil information for all locations

Location	Soil series	Soil classification	Soil texture
Burlington	Taintor	Fine, montmorillonitic, mesic Typic Argiaquolls	Silty clay loam
Nashua	Kenyon	Fine-loamy, mixed, mesic Typic Hapludolls	Loam
Newell	Clarion	Fine-loamy, mixed, mesic Typic Hapludolls	Loam
Sutherland	Galva	Fine-silty, mixed, mesic Typic Hapludolls	Silty clay loam
Crawfordsville	Kalona	Fine, montmorillonitic, mesic Typic Haplaquolls	Silty clay loam
	Nira	Fine-silty, mixed, mesic Typic Hapludolls	Silty clay loam

A randomized complete block split-plot design with three replications was used at Sutherland, where only corn–soybean rotation was used. Tillage systems (NT, RT, and CP) were randomly assigned to the main plots, lime rates (0, 560, 1120, 2240, 4480, and 6720 kg ha^{-1}) were assigned to the split-plots. In corn–soybean rotations at all locations, two adjacent areas in the same field were used simultaneously each year, so that both corn and soybean were evaluated in every year.

Corn grain yield was determined on a plot (or split-plot, if applicable) basis. Grain samples were collected for determination of moisture content, and corn yield was adjusted to a moisture content of 155 g kg^{-1}.

Economic return in this report refers to the return to land and management. Economic return was calculated based on actual field operations (such as tillage practices, fertilizer and herbicide applications, etc.) and fertilizer rates. However, other costs including seed, herbicide, lime, and crop insurance were based on Duffy and Smith (2002). The time required by each field operation was based on Hanna (2001), using machine sizes of intermediate field capacity. The labor cost (assuming $ 8.00 h^{-1}) included not only the actual fieldwork, but also time for maintenance, travel, and other activities related to crop production. A corn grain price of $ 86.55 per metric ton was assumed each year.

2.3. Statistical analysis

Yield and economic return data of corn were analyzed for each location separately. Corn data that were collected from the two adjacent areas in the same field in a corn–soybean rotation were combined and analyzed as one data set. To evaluate the stepwise time response of corn yield and economic return to NT in long-term studies, the first 4- to 5-year period was referred to as the beginning phase, the second 4- to 5-year period represented the intermediate phase, and the third and fourth 4- to 5-year periods were both referred to as the final phase. Statistical analyses were conducted separately for each of these three phases.

Corn yield and economic return were also analyzed across years, using an analysis of variance appropriate for a randomized complete block design at all locations except Sutherland, where the analyses were based on a split-plot design.

A separate analysis of variance was performed for each dependent variable. If the treatment effects were statistically significant according to the *F*-test, then mean separations for the treatment effects were made by using Fisher's protected least significant difference (LSD) test; otherwise, no mean separation was performed. Probability levels less than 0.05 were categorized as significant.

Linear regression analysis using annual yield as the dependent variable and the length of time (number of years) since tillage adoption as the independent variable was conducted to examine the changes of yield with time under each tillage system in both crop rotations at each location. All analyses were accomplished by using the SAS system for Windows V8 (SAS Institute, 2002).

3. Results

3.1. Stepwise time response of yield and economic return

3.1.1. Beginning phase (first 4–5 years)

No tillage produced yield only 3% less than MP at Burlington, although it was statistically significant (Table 2). At Nashua, the yield difference between NT and MP was not significant in a corn–soybean rotation, but NT yielded 8% less than MP in continuous corn. No tillage had equal or greater yield than RT regardless of crop rotation and location. Compared with CP, NT produced a similar yield in a corn–soybean rotation at Nashua, but 4 and 10% less yield at Sutherland and Crawfordsville, respectively. For continuous corn, yield under NT was less than with CP at Nashua, but not at Crawfordsville.

Economic return for NT corn was statistically identical to that under MP at Burlington (Table 2). At Nashua, NT had an economic return $ 39 ha^{-1} greater than MP in a corn–soybean rotation, but similar to MP in continuous corn. No tillage gave equal or greater economic return compared with RT regardless of crop rotation and location. Economic return for NT and CP did not differ at any location regardless of crop rotation except for the corn–soybean rotation at Crawfordsville. Overall, NT was competitive to MP, RT, and CP during the beginning phase at most locations

Table 2
Corn yield and economic return of no tillage compared with other tillage systems (RT, ridge tillage; CP, chisel plow; MP, moldboard plow; RDT, reduced tillage) during the beginning phase (first 4–5 years)[a]

Location	Rotation	Yield[b]						Economic return[b]					
		F-test	NT ($Mg\,ha^{-1}$)	RT ($Mg\,ha^{-1}$)	CP ($Mg\,ha^{-1}$)	MP ($Mg\,ha^{-1}$)	RDT ($Mg\,ha^{-1}$)	*F*-test	NT ($\$\,ha^{-1}$)	RT ($\$\,ha^{-1}$)	CP ($\$\,ha^{-1}$)	MP ($\$\,ha^{-1}$)	RDT ($\$\,ha^{-1}$)
Burlington	Corn–soybean	**	8.19 c			8.44 b	8.69 a	**	154 b			135 b	179 a
Nashua	Corn–soybean	**	9.50 a	9.20 b	9.60 a	9.62 a		**	217 a	191 bc	201 ab	178 c	
	Continuous corn	***	8.69 c	8.76 bc	9.00 b	9.44 a		ns[c]	160	166	163	177	
Sutherland	Corn–soybean	*	9.17 b	9.23 b	9.57 a			**	306 ab	289 b	326 a		
Crawfordsville	Corn–soybean	**	8.32 b	8.41 b	9.23 a			***	232 b	217 b	296 a		
	Continuous corn	ns	6.73	6.93	7.11			ns	60	55	80		

[a] Time period for Burlington, Nashua, Sutherland, and Crawfordsville is 1980–1984, 1978–1982, 1994–1998, and 1990–1994, respectively.
[b] Means within a row within yield or economic return followed by different letters are significantly different at $P = 0.05$ according to Fisher's protected LSD test.
[c] Not significant.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

in terms of yield, but more so in terms of economic return.

3.1.2. Intermediate phase (second 4–5 years)

No tillage produced significantly less yield than MP at Burlington and in both crop rotations at Nashua (Table 3). Yield under NT was similar to that under RT at all locations, except in continuous corn at Nashua. No tillage produced yield less than CP in both rotations at Nashua and at Sutherland. However, no significant yield difference was observed between NT and CP at Crawfordsville, irrespective of crop rotation.

No significant difference in economic return was observed between NT and MP, RT, or CP in this phase except the \$ 49 ha^{-1} lower return under NT than under CP at Sutherland (Table 3). In general, NT performance relative to MP, RT, and CP systems was similar in the intermediate phase compared with the beginning phase, in terms of both yield and economic return.

3.1.3. Final phase (third and fourth 4–5 years)

Trends of the third 4- to 5-year phase were similar to those observed in the beginning and intermediate phases (Table 4). Yield under NT was 5% less than MP at Burlington. Significant yield difference between NT and MP, RT, or CP was not observed in a corn–soybean rotation, but was observed in continuous corn, at both Nashua and Crawfordsville.

Economic return for NT corn did not differ from that under MP, RT, and CP at either Burlington or Crawfordsville in the third 4–5-year phase (Table 4). At Nashua, NT gave greater economic return than MP in a corn–soybean rotation, but not in continuous corn. No tillage had a similar economic return as RT and CP in a corn–soybean rotation regardless of location, but less economic return than RT and CP in continuous corn at Nashua. Identical trends as those in the third 4–5-year phase were observed in the fourth 4–5-year phase for both yield and economic return at Nashua (Table 4).

In addition to the stepwise response analysis for corn yield and economic return, annual yield was linearly regressed against time since tillage adoption. The results showed no significant difference in corn yield response to NT and other tillage systems (data not presented) regardless of rotation and location. Therefore, tillage did not affect the stability of corn performance with time.

In summary, neither yield nor economic return showed any significant improvement under NT relative to other tillage systems from the early phase to intermediate and final phases of management. No tillage performed equally well during the early years since tillage adoption relative to later years. The yield difference between NT and other tillage systems was mostly small (within 5%) in a corn–soybean rotation regardless of location. Economic return for NT corn was usually equal to or greater than those under other tillage systems in both crop rotations. This finding suggests that the differences in yield and economic return between NT and other tillage systems were not affected by the length of time since they were adopted.

Results of the Nashua study showed that NT performed much better in a corn–soybean rotation than in continuous corn, relative to other tillage systems, in terms of both yield and economic return in all phases (Tables 2–4). This observation suggests that a corn–soybean rotation could improve NT corn production, and that this positive rotation effect was consistent with time. However, the rotation benefit was generally not observed at Crawfordsville. In addition, corn in rotation with soybean produced greater yield and economic return than continuous corn irrespective of tillage system at all locations, although this effect was not statistically analyzed.

3.2. Average response of yield and economic return

At Burlington, NT produced corn yield 5% less than MP in a corn–soybean rotation averaged across 13 years (Table 5). At Nashua, corn yield under NT was similar to that under MP in a corn–soybean rotation, but 11% less in continuous corn. At Newell, the yield difference between NT and MP was only 4%, even though this difference was statistically significant. Overall, the yield difference between NT and MP was small (within 5%) at all locations within a corn–soybean rotation. No tillage gave similar economic return as MP at Burlington and Newell (Table 5). Economic return for NT was 27% greater than for MP in a corn–soybean rotation, but 28% less in continuous corn at Nashua. It is apparent that NT had equal or greater economic return than MP in a corn–soybean rotation at all locations.

Ridge tillage is a commonly used conservation tillage practice in Iowa. At Nashua, Sutherland, and

Table 3
Corn yield and economic return of no tillage compared with other tillage systems (RT, ridge tillage; CP, chisel plow; MP, moldboard plow; RDT, reduced tillage) during the intermediate phase (second 4–5 years)[a]

Location	Rotation	Yield[b]						Economic return[b]					
		F-test	NT ($Mg\,ha^{-1}$)	RT ($Mg\,ha^{-1}$)	CP ($Mg\,ha^{-1}$)	MP ($Mg\,ha^{-1}$)	RDT ($Mg\,ha^{-1}$)	*F*-test	NT ($\$\,ha^{-1}$)	RT ($\$\,ha^{-1}$)	CP ($\$\,ha^{-1}$)	MP ($\$\,ha^{-1}$)	RDT ($\$\,ha^{-1}$)
Burlington	Corn–soybean	***	8.30 b			9.01 a	8.97 a	**	164 b			185 ab	203 a
Nashua	Corn–soybean	*	8.27 b	8.31 b	8.63 a	8.65 a		ns[c]	110	113	117	95	
	Continuous corn	***	6.98 c	7.34 b	7.50 b	7.92 a		ns	12	44	31	45	
Sutherland	Corn–soybean	***	9.29 b	9.48 b	10.01 a			***	316 b	309 b	364 a		
Crawfordsville	Corn–soybean	ns	8.71	8.68	8.75			ns	266	243	255		
	Continuous corn	ns	6.86	7.14	7.04			ns	71	80	73		

[a] Time period for Burlington, Nashua, Sutherland, and Crawfordsville is 1984–1988, 1982–1986, 1998–2001, and 1994–1998, respectively.
[b] Means within a row within yield or economic return followed by different letters are significantly different at $P = 0.05$ according to Fisher's protected LSD test.
[c] Not significant.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 4
Corn yield and economic return of no tillage compared with other tillage systems (RT, ridge tillage; CP, chisel plow; MP, moldboard plow; RDT, reduced tillage) during the final phase (third and fourth 4–5 years)[a]

Location	Rotation	Yield[b]						Economic return[b]					
		F-test	NT ($Mg\,ha^{-1}$)	RT ($Mg\,ha^{-1}$)	CP ($Mg\,ha^{-1}$)	MP ($Mg\,ha^{-1}$)	RDT ($Mg\,ha^{-1}$)	*F*-test	NT ($\$\,ha^{-1}$)	RT ($\$\,ha^{-1}$)	CP ($\$\,ha^{-1}$)	MP ($\$\,ha^{-1}$)	RDT ($\$\,ha^{-1}$)
Burlington	Corn–soybean	***	8.54 b			9.01 a	8.90 a	ns[c]	185			185	197
Nashua	Corn–soybean	ns	8.74	8.64	8.76	8.61		**	151 a	142 a	128 a	91 b	
	Continuous corn	**	7.27 b	7.83 a	7.95 a	8.01 a		*	37 b	86 a	72 a	53 ab	
Crawfordsville	Corn–soybean	ns	9.48	9.30	9.45			ns	332	298	315		
	Continuous corn	*	8.16 b	8.42 a	8.44 a			ns	184	193	194		
Nashua	Corn–soybean	ns	9.64	9.60	9.73	9.47		***	229 a	226 a	212 a	164 b	
	Continuous corn	***	7.91 b	8.56 a	8.91 a	8.87 a		*	93 b	150 a	155 a	127 ab	

[a] The results are from the third 4- to 5-year period for all locations except the last two rows that are the results of the fourth 4- to 5-year period for Nashua. The third 4- to 5-year period for Burlington, Nashua, and Crawfordsville is 1988–1992, 1986–1989, and 1998–2001, respectively. The fourth time period for Nashua is 1989–1992.

[b] Means within a row within yield or economic return followed by different letters are significantly different at $P = 0.05$ according to Fisher's protected LSD test.

[c] Not significant.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

Table 5
Corn yield and economic return of no tillage compared with other tillage systems (RT, ridge tillage; CP, chisel plow; MP, moldboard plow; RDT, reduced tillage) averaged across years

Location	Crop rotation	Number of years	Tillage	Yield (Mg ha^{-1})[a]	Economic return ($ ha^{-1})[a]
Burlington	Corn–soybean	13	NT	8.59 b	189 b
			RDT	9.05 a	210 a
			MP	9.04 a	188 b
			F-test	***	**
Nashua	Corn–soybean	15	NT	9.03 bc	175 a
			RT	8.90 c	164 a
			CP	9.23 a	169 a
			MP	9.15 ab	138 b
			F-test	***	***
	Continuous corn	15	NT	7.71 d	75 b
			RT	8.07 c	104 a
			CP	8.29 b	102 a
			MP	8.61 a	105 a
			F-test	***	***
Newell	Corn–soybean	6	NT	8.83 b	251
			CP	9.10 ab	251
			FC	9.17 a	272
			TP	8.82 b	247
			MP	9.16 a	239
			F-test	*	ns[b]
Sutherland	Corn–soybean	8	NT	9.19 b	340 a
			RT	9.35 b	307 b
			CP	9.72 a	299 b
			F-test	***	***
Crawfordsville	Corn–soybean	12	NT	8.70 b	265 a
			RT	8.68 b	243 b
			CP	9.06 a	282 a
			F-test	**	***
	Continuous corn	12	NT	7.23 b	103
			RT	7.44 a	104
			CP	7.48 a	112
			F-test	*	ns

[a] Means within a column for each crop rotation at a location followed by different letters are significantly different at $P = 0.05$ according to Fisher's protected LSD test.
[b] Not significant.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Crawfordsville, the yield difference between NT and RT (or RT/AL) was not statistically significant in a corn–soybean rotation (Table 5). However, in continuous corn, yield under NT was significantly less than under RT (or RT/AL) at both Nashua and Crawfordsville. Economic return for NT was equal to or greater than that for RT at all locations under a corn–soybean rotation (Table 5). In continuous corn, economic return with NT was significantly less than under RT at Nashua, but statistically identical at Crawfordsville.

Chisel plow is another commonly used conservation tillage system in Iowa. No tillage consistently produced significantly less yield than CP at all locations except at Newell, no matter which crop rotation was used (Table 5). However, the yield difference between the two tillage systems was generally small, ranging from 2 to 7%. Economic return under NT was statistically identical to or greater than that under CP at all locations in both crop rotations, except in continuous corn at Nashua (Table 5).

Corn yield under NT was significantly less than under RDT and FC, but similar to that with TP. Economic return of NT was approximately \$ 10 ha^{-1} less than with RDT, but did not differ from that under FC or TP.

4. Discussion

Both the stepwise time response (Tables 2–4) and linear regression analyses (data not presented) suggested no significant improvement in either yield or economic return of corn with time under NT since its adoption. This observation agrees with that reported by Chase and Duffy (1991) in a 10-year tillage study at Nashua, Iowa, where only linear regression analysis was conducted. However, other research showed improvement in NT corn yield with time on soils with low organic matter (Griffith et al., 1988). Dick et al. (1991) reported in Ohio that after 18 years of tillage practices, the negative impact of NT on corn yield on a poorly drained soil was greatly decreased compared with earlier years, and the corn yield advantage associated with NT relative to MP on a well-drained soil became even more pronounced. West et al. (1996) reported that yield reduction due to NT compared with other tillage systems on poorly drained soils was likely greater with time for continuous corn; but changed little with time in a corn–soybean rotation. Our results are somewhat surprising in that there was no yield increase with time regardless of tillage system even though corn cultivars, management practices, and farming machinery were continuously improved during the entire study period.

Corn in rotation with soybean yielded greater than continuous corn regardless of tillage system and location in this study when data were grouped into 4- to 5-year phases or combined across all growing seasons. These results are consistent with the literature. Lund et al. (1993) reported a 10% increase in corn yield averaged over NT and MP in a corn–soybean rotation compared with continuous corn. Other reports have documented that corn in a corn–soybean rotation had less yield loss due to NT than in continuous corn (Meese et al., 1991; West et al., 1996).

It is well documented that NT results in improved soil physical, chemical, and biological properties. Collectively or individually, these changes may influence corn growth and yield. The changes can be detrimental, neutral, or beneficial for crop growth and yield, depending on soil condition, climate, and management practices. Lower corn yield under NT relative to other tillage systems in our study was observed predominantly in continuous corn, on poorly drained soils, and with cooler growing seasons. The negative effects of NT on corn growth under these conditions included slow and uneven emergence and delayed growth.

Economic return for corn production is affected by not only grain yield but also the cost of seed, herbicide, fertilizer, machinery, and labor. In general, NT systems require lower production cost in labor, fuel, and machinery, but greater cost in pesticides and intensive management to maintain or increase yield. Overall, NT often has a lower production cost than other tillage systems. Our results suggest that greater yield alone does not translate directly into greater economic return, and a small yield loss with NT relative to other tillage systems does not necessarily mean a significant decline in economic return. For example, total production cost under NT was \$ 25–50 ha^{-1} lower than MP. Even though NT produced corn yield of 0.6 Mg ha^{-1} less than MP, the economic return for the two tillage systems was similar.

Converting from one management system to another requires learning and adopting new farming techniques, operating specialized equipment, and handling different weed control products. Different producers may obtain considerably different yield and economic return from NT because they are proficient in different crop and soil management techniques, but not necessarily all. The adoption of NT will most likely increase as producers become familiar with new management practices, and if labor costs increase significantly.

5. Conclusions

Differences in both corn yield and economic return between NT and other tillage systems did not change markedly with time. Therefore, the competitiveness of NT relative to other tillage systems in the early years (first 4–5 years) was as strong as that later on. In general, a yield decline with NT compared with other tillage systems was within 5% for a corn–soybean rotation, but often greater in continuous corn. However, NT generally had economic return equal to or greater than other tillage systems in each 4- to 5-year phase and over the entire study period. Therefore, the adoption of NT systems can be accomplished without lowering economic return from both short- and long-term perspectives.

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