CORN AND SOYBEAN RESPONSE TO TILLAGE AND ROTATION SYSTEMS ON A DARK PRAIRIE SOIL: 25 YEAR REVIEW

T. J. Vyn*, 1150 Lilly Hall, Department of Agronomy, Purdue University, West Lafayette, IN 47907-1150, tvyn@purdue.edu

T.D. West, 1150 Lilly Hall, Department of Agronomy, Purdue University, West Lafayette, IN 47907-1150, twest@purdue.edu

G. C. Steinhardt, 1150 Lilly Hall, Department of Agronomy, Purdue University, West Lafayette, IN 47907-1150, gsteinhardt@purdue.edu

ABSTRACT

Few research studies have evaluated crop response to conservation tillage systems for 25 yr or more. Our objectives were to determine the effect of tillage and rotation systems on corn (Zea mays L.) and soybean (Glycine max L.) yield trends over a 25-yr period on a dark prairie soil. The experiment was conducted from 1975 to 1999 on a Chalmers silty clay loam in north-central Indiana. Plow, chisel, ridge and no-till systems were compared in continuous corn, continuous soybean, corn after soybean, and soybean after corn rotations. Both corn and soybean yields were increased by 10 to 11% due to rotation when averaged over the four tillage systems. However, the highest response to rotation (19%) was observed in no-till corn, while plowed corn yielded just 5% higher in rotation. Corn yield reductions with no-till, relative to plow, averaged 14% in continuous corn and just 3% in rotation corn. No-till yield reductions appeared to increase with time in continuous corn, and remain relatively consistent with time in rotation corn. Soybean yield reductions with no-till, relative to plow, averaged 5% in both continuous soybeans and rotation soybeans. Soybean no-till yield reductions became less evident in the last 10 yr period. Thus, the long-term no-till system resulted in a major yield reduction only in continuous corn. Chisel plowing resulted in yield reductions, relative to moldboard plowing, of 3% in corn and 5% in soybeans only with monoculture production. Continuous no-till production is recommended, even on this dark prairie soil, when corn and soybeans are grown in rotation.

INTRODUCTION

During the past 20 years, the use of conservation tillage systems has increased rapidly in the central and eastern sections of the Corn Belt of the United States. Adoption of no-till has been particularly rapid for soybeans in the last 10 years, but no-till corn acreage has declined somewhat from its peak in the middle 1990's. In 1998, for instance, no-till was used on 54% of the soybean acreage but only 16% of the corn acreage in Indiana (CTIC, 1998). Hill (1998) observed that just 16% of the surveyed fields in Indiana and Illinois were in continuous no-till, while some 30% of the surveyed fields were involved in rotational tillage (e.g. no-till soybeans followed by intensive and full-width tillage systems before corn).

Researchers will readily acknowledge that no-till corn is best adapted to soils that are well drained (Dick et al., 1991; Griffith et al., 1988). No-till is often less likely to result in corn yields equal to those with conventional tillage (whether moldboard or chisel plowing) on fine-textured and (or) poorly drained soils (Dick et al., 1991; Griffith et al., 1988; Opoku et al., 1997). Yet, even then, the long-term advantages of continuous no-till to soil structure, plus the equipment and labor cost reductions associated with no-till, may still be sufficient reasons to justify maintaining a field in continuous no-till through its entire cropping sequence.

No-till soybean yields are less likely to be lower than those with conventional tillage, even on poorly drained soils. Thus, for instance, research in Iowa (Brown et al., 1989) and Indiana (West et al., 1996) have generally found few instances of soybean yield reductions with no-till relative to moldboard plowing. Soybean yield reductions are most apt to occur if soybean varieties are susceptible to disease which is more prevalent in no-till (Adee et al., 1994), and if soybeans are planted no-till into high residue cover situations in more northern latitudes (Vyn et al., 1999).

No-till corn is most likely to succeed when planted in rotation with other crops such as soybeans (Dick et al., 1991; Chase and Duffy, 1991; West et al., 1996), or even whole-plant silage corn (Janovicek et al., 1998) relative to continuous grain corn. The extent of the no-till corn yield reduction following corn on poorly drained soil was affected by the positioning of the previous crop residue relative to the row area (Kaspar et al., 1990). Surface residue placement has also influenced no-till corn yields following winter wheat (Opoku et al., 1997).

Most tillage studies are conducted for duration of 10 years or less. Few experiments have been conducted for over 20 years. Farmer confidence in continuous no-till adoption would be improved if it could be demonstrated that no-till benefits can accrue with time, and that there are fewer yield risks in a continuous no-till versus a short-term no-till cropping program - even on soils with inherently poor or moderate drainage. This study updates our experiences with corn and soybean response to four tillage systems, in either continuous or rotational cropping, over the last 25-year period on one such poorly drained soil. Our objectives were (i) to determine the effect of tillage and rotation systems on corn and soybean growth and yield responses, and (ii) to determine the crop yield trends associated with system performance over time.

MATERIALS AND METHODS

A long-term rotation and tillage experiment was established at the Purdue University Agronomy Research Center near Lafayette, IN (40° 28' N Lat.) in 1975. The soil was a Chalmers (fine-silty, mixed, mesic Typic Endoaquoll) silty clay loam with approximately 4.0% organic matter in the surface 30 cm, developed under prairie vegetation. The experimental area had had less than 2% slope and was systematically tile drained at 20-m intervals.

The experiment was established in a split-plot design with three replications; rotations were main plots and tillage treatments were sub-plots. Rotation treatments were continuous corn, corn following soybean, soybean following corn, and continuous soybeans. The tillage plots were each 9.14 m (12 corn rows) wide and 46 m long. The four tillage systems included:

1. Fall moldboard plowing to 20 cm, with one disking and one field cultivation to 10 cm in the spring prior to planting (plow system).
2. Fall chiseling to 20 cm, with one disking and one field cultivation to 10 cm in the spring prior to planting (chisel system). From 1974 through 1986, stalks were chopped and 5-cm-wide chisel points were used. From 1987 to 1999, a coulter chisel with 10-cm points was used, with no stalk chopping.
3. Ridge-till planting on ridge tops following removal of 2 to 5 cm of soil and residue from the ridge with a sweep, double disk, or horizontal disk mounted on the planter for a one-pass tillage-planting operation (ridge-till system). Large sweeps or disks were used to re-form ridges at cultivation when corn was about 40 cm tall. In soybean, ridges were re-formed after crop harvest in the fall. The planter was inadequately equipped to center on ridge tops in years 1975 through 1979, resulting in reduced stands and yield potential during the period.
4. No-till planting with a single fluted or bubble coulter to cut through residues and loosen soil ahead of standard planter units. Since 1997, tined row cleaners have been used in place of no-till coulters in front of the standard seed disc openers.

Soybeans were planted in wide rows with the same row-crop planter as for corn from 1975 to 1994. Starting in 1995, soybeans were drilled in 19-cm rows for all treatments but ridge-till. Each year all corn plots were planted on the same day and all soybean plots were planted on the same day.

Starter fertilizer was applied in a 5 cm by 5 cm for all side band corn plots, but not for soybeans. The starter has always included nitrogen (N) and since 1992 the N rate in starter has been over 35 kg ha^{-1}. The N source for corn was anhydrous ammonia; it was applied either pre-plant or side-dress at rates of at least 190 kg ha^{-1}. Phosphorous, potassium and lime were surface-applied as needed, generally before primary tillage operations in the fall.

Burndown herbicides were applied to control vegetation before planting when needed. Pre-emergence herbicides were applied at planting or soon after planting. Post applied herbicides were used for weed escapes only when needed, and some plots were even occasionally hand weeded to insure that weeds did not limit crop yield. Insecticides were applied at planting for corn rootworm control in all corn plots since 1975.

Four corn hybrids and eight soybean varieties have been used during the 25 years of this project. Corn seeding rate was gradually increased from 60,000 ha^{-1} in 1975 to

76,000 ha^{-1} in 1999. More detailed production practices for this experiment, as well as weather information, are provided by Griffith et al. (1988) and West et al. (1996).

Planting dates ranged from April 25 to May 22 for corn, and from May 3 to May 28 for soybeans (Table 1). All 76-cm row treatments except no-till were inter-row cultivated once. Grain was harvested from the center four rows of each plot with a commercial four-row (or 3.3 m grain head) combine with weight and percentage moisture determinations used to calculate yield. Analysis of variance for yields included years as a fixed variable, since yield trends developed with time for certain tillage treatments. Additional data taken annually included plant population at 4 wk after planting, plant height at 4 and 8 wk, and grain moisture at harvest.

Table 1. Planting dates for corn and soybean. Chalmers silty clay loam, ARC.

	Year	Corn	Soybean		Year	Corn	Soybean
1	1975	5/2	5/6	14	1988	4/26	5/12
2	1976	4/29	5/10	15	1989	4/25	5/12
3	1977	5/12	5/6	16	1990	4/25	5/21
4	1978	5/3	5/19	17	1991	5/10	5/3
5	1979	5/9	5/17	18	1992	5/5	5/7
6	1980	5/5	5/15	19	1993	5/11	5/12
7	1981	5/22	5/28	20	1994	4/26	5/17
8	1982	4/30	5/11	21	1995	5/22	6/1
9	1983	5/10	5/12	22	1996	5/31	6/21
10	1984	5/2	5/14	23	1997	4/29	5/16
11	1985	4/25	5/16	24	1998	5/14	5/18
12	1986	4/29	5/28	25	1999	5/12	5/21
13	1987	5/5	5/7				

RESULTS AND DISCUSSION

Corn Response

In continuous corn, 25 yr average chisel yields were approximately 3% lower relative to moldboard plowing, but no-till corn yields were reduced 14% (Table 2). Five-year moving average yield comparisons (Fig. 1) indicate that no-till yield reductions became greater with time. Causes of the overall no-till yield reduction, as well as its increasing disparity with time, are not clear. Reduced plant populations may have been a factor in 1989 and 1994 (West et al., 1996), but overall plant populations have not been significantly lower for no-till in 9 of the last 10 years (data not presented). Some other studies have observed that no-till continuous corn yields can increase, relative to other tillage systems, on low OM soils (Griffith et al., 1988) and with low rainfall (Dickey et al., 1994). On this dark poorly drained soil, no-till corn yields did not improve with time, and 1998 results appear to be an exception to the recent trend. Possible factors in the yield reduction with no-till include corn root disease (Tiarks, 1977), lower soil temperatures (Griffith et al., 1992), delayed root development (Mackay et al., 1985), increased soil strength in previous wheel tracks (Larney and Kladivko, 1989), and an increase over time in soil microorganisms that might be antagonistic to corn (Nakatsu et al., 2000). However, there has been no indication that one soil factor is consistently associated with the grain yield reduction. Griffith et al. (1988) observed previously that tillage differences in accumulated soil GDD from planting to either 4 weeks or 8 weeks after planting were very poorly correlated with continuous corn yield differences in no-till versus plow.

Following soybeans, chisel and ridge corn yields were at least equal to plowed corn yield, but no-till yield was reduced by 3% (Table 2). The slight yield reduction with no-till corn after soybeans has been very consistent over time (Fig. 2). Final plant populations for plow and no-till corn were similar after soybeans in rotation (West et al., 1996). The much smaller yield reduction associated with no-till after soybeans versus grain corn has also been observed by other researchers. The yield reduction is small enough that continuous no-till in a corn-soybean rotation is economically superior to the plow system. It is also interesting to note that there was much less year-to-year variation in no-till versus plowed yield differences for rotation corn (Fig. 2) than there was for continuous corn (Fig. 1).

Table 2. Corn yield response to rotation and tillage systems on silty clay loam (1975-1999).

Tillage System	Corn / Soybean		Continuous Corn		Yield Gain for Rotation (%)
	$Mg\ ha^{-1}$	% of Plow	$Mg\ ha^{-1}$	% of Plow	
Plow	11.0 a‡	100	10.5 a	100	5
Chisel	11.1 a	100	10.2 b	97	9
Ridge†	11.4	103	10.4	99	10
No-till	10.8 b	97	9.0 c	86	19

† Average of 1980 to 1999 only, so not included in the statistics of means comparisons.

‡ Within a rotation, data followed by the same letter are not significantly different at P=0.05.

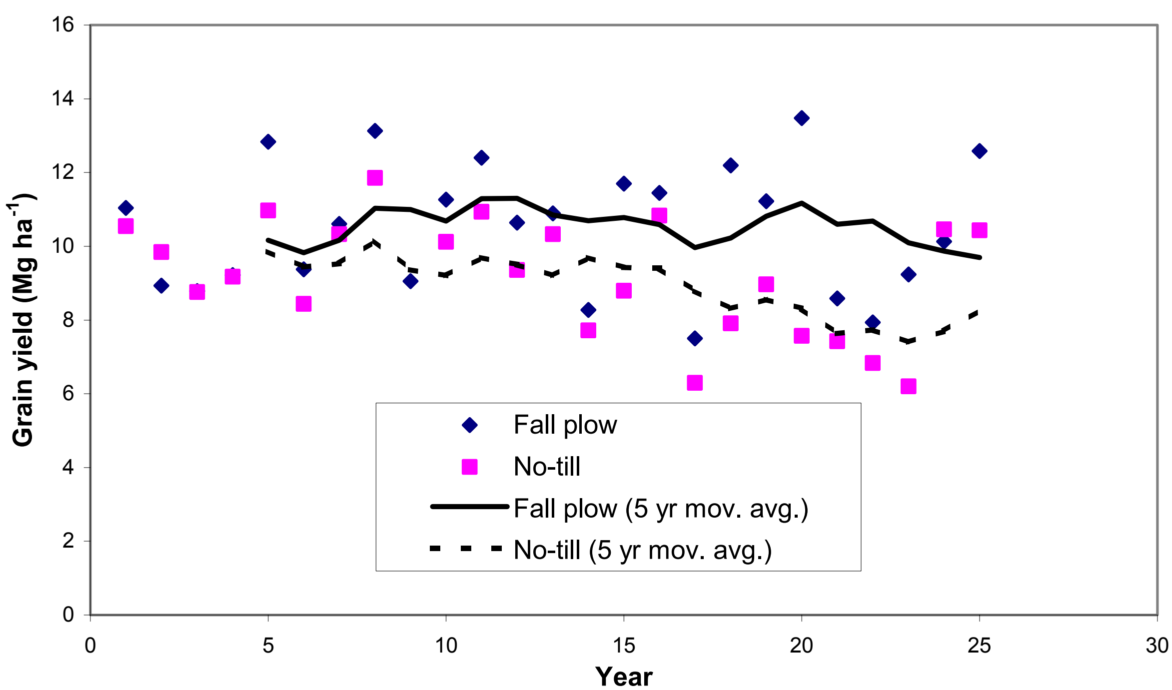

Fig. 1 Continuous corn yields with plow versus no-till systems on Chalmers soil (1975-99).

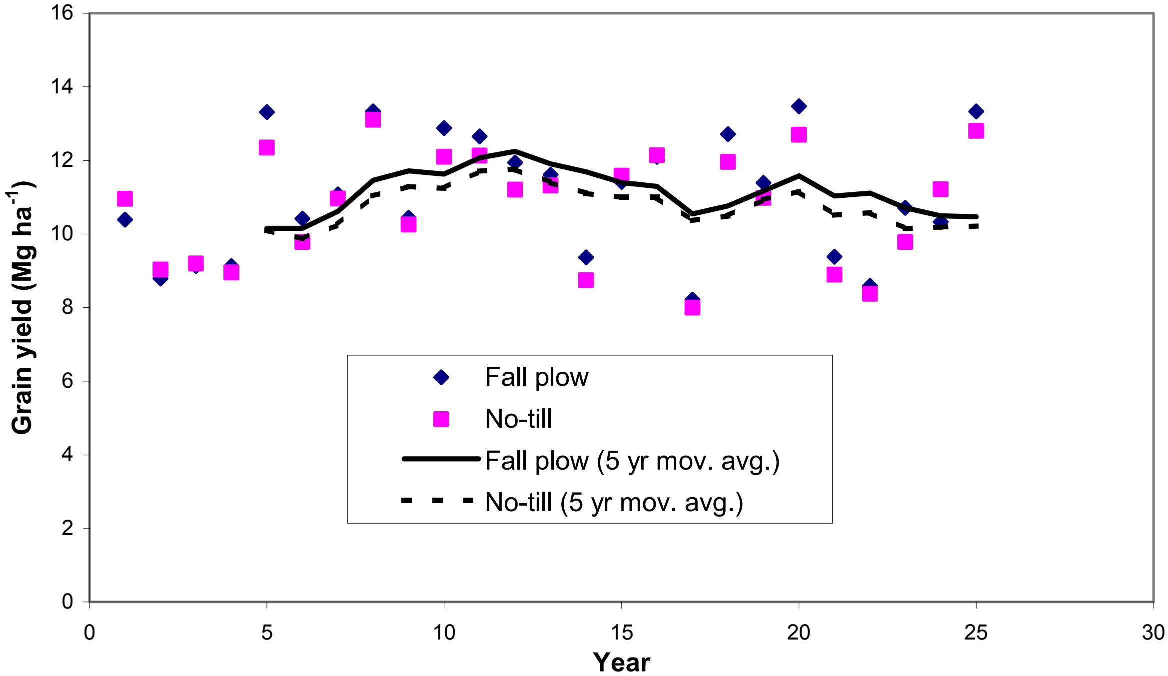

Fig. 2 Corn yields after soybeans with plow versus no-till systems on Chalmers soil (1975-99).

Soybean Response

No-till soybean yields were reduced by 5%, relative to plowing, in both rotation and continuous cropping systems (Table 3). Chisel soybean yields were intermediate for soybeans after corn, but similar to no-till in continuous soybeans. Both in rotation and monoculture, no-till soybean yields were essentially equal to plowed soybean yields over the last 10 years (Fig. 3 and 4). The yield trend lines in the latter two figures indicate that no-till yields achieved equivalency with plowed yields even before narrow rows were adopted in 1995. The trend lines since 1995 also indicate that no-till is less likely to maintain yield consistency with plowed soybeans when grown in monoculture versus in rotation with corn.

Table 3. Soybean yield response to rotation and tillage systems on a silty clay loam (1975-99).

Tillage System	Corn / Soybean		Continuous Soybeans		Yield Gain for Rotation (%)
	Mg ha^{-1}	% of Plow	Mg ha^{-1}	% of Plow	
Plow	3.50 a‡	100	3.21 a	100	9
Chisel	3.42 ab	98	3.05 b	95	12
Ridge†	3.37	96	2.99	93	13
No-till	3.32 b	95	3.06 b	95	9

† Ridge-till yield are from 1980 to 1999 only, and are consistently for 76-cm wide row, therefore, ridge values are not included in statistical comparisons among tillage systems.

‡ Within a rotation, data followed by the same letter are not significantly different at P=0.05.

Reasons for the generally reduced no-till soybean yields, and the relative improvement for no-till planting in the last decade, are not clear. However, the relative disease susceptibilities of the various varieties used may have been a factor. Both phytophthora root rot (*Phytophthora* megasperma var. sojoe) and sudden death syndrome (*Fusarium* solani) strains are present in these no-till plots (Dr. S. Abney, personal communication). Soybean cyst nematode (*Heterodera* glycines Ichinohe) damage to soybean plants was also visually evident in 1998 and 1999. Soybean varieties vary in their resistance or tolerance to these and other diseases; recent soybean variety changes in this experiment occurred in 1990, 1993, 1995, and 1998. Varieties resistant to the most common races of phytophthora root rot have been used since 1981, and plant stand establishment has not been less in no-till than in plowed soybeans in either rotation system for the past 10 years (data not presented). Overall, soybean populations throughout the 25 yr study have been consistently higher (data not presented) than those necessary to achieve maximum yield in either 76-cm or 19-cm row widths (Christmas, 1994).

Rotation soybean yields averaged higher than continuous soybean yields (Table 2), and the effect was consistent for all four tillage systems. The 25 yr average response (10.6%) to rotation presented in this paper is even higher than the 7.6% yield gain reported for the first 20 years of this study (West et al., 1996). Wide (76 cm) row widths were used consistently until 1994. In contrast to the corn response to rotation, the yield gain due to rotation with no-till and plowed soybeans were similar (Table 2). Soybean annually rotated with corn also yielded 10% more in long-term conventionally tilled experiments in Minnesota and Wisconsin (Porter et al., 1997).

Examination of some of the year-to-year variation in yields due to tillage (Fig. 3 and 4) reveals that no-till soybean yields were most likely to surpass plowed yields when drought stress occurred during midsummer (1991 and 1998) than when drought stress occurred in early May (e.g. 1988) (weather data not presented). No-till soybeans aren't inherently more stress tolerant than conventionally tilled soybeans, and practicing no-till continuously for 25 years doesn't guarantee higher soybean yields or less negative impact from growing season stresses than continuous moldboard plowing. However, the response patterns of soybeans to drought stress might have been entirely different if significant topsoil loss had occurred in the conventional tillage system, or if the experiment had been initiated on a lower organic matter soil.

Yield Trend With Time

It is interesting, and discouraging to agronomists, that both overall corn and soybean yields have not improved in the 25 yr period. Yield trends for all figures (Fig. 1 to 4) do not increase with time despite an overall increase in Indiana state average corn yields of some 100 kg ha^{-1} yr^{-1} since 1980 (Indiana Agricultural Statistics Service). Certainly unusual weather conditions had an impact on crop yields during the past 15 yr. Thus, for instance, low corn and soybean yields in 1987 and 1991 (dry years) and 1996 (excessively wet spring and resultant late planting) have contributed to the general lack of yield appreciation. But even if these anomalies are overlooked, the yields achieved do not seem to be increasing at the same rate as the improvements in genetic yield potential with more modern cultivars would suggest. Experiment mean corn yields (past 5 yr) were 150% of state average yields (5 yr trend line) in 1980, but only 130% of state average yields in 1999. Similarly for soybeans, experiment mean yields (past 5 yr) were

146% of state average yields in (5 yr trend line) in 1980, and 126% of state average yields in 1999.

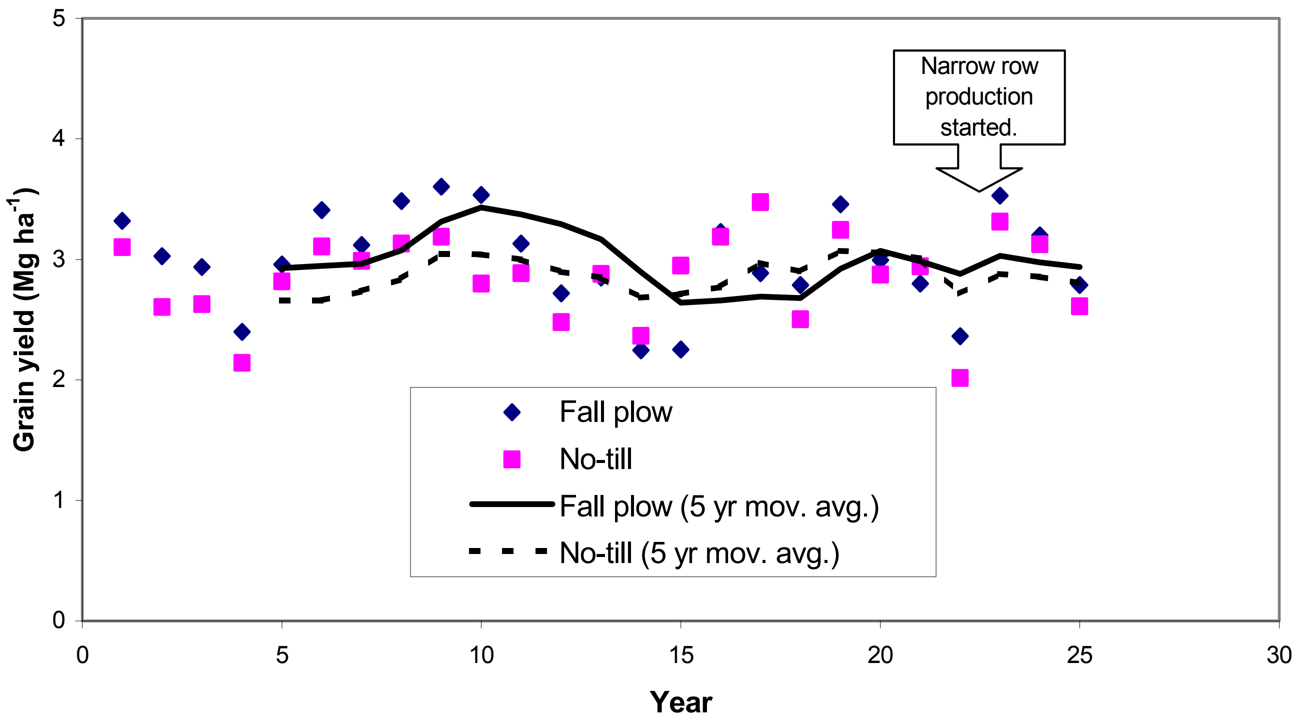

Fig. 3 Continuous soybean yields with plow versus no-till systems on Chalmers soil (1975-99).

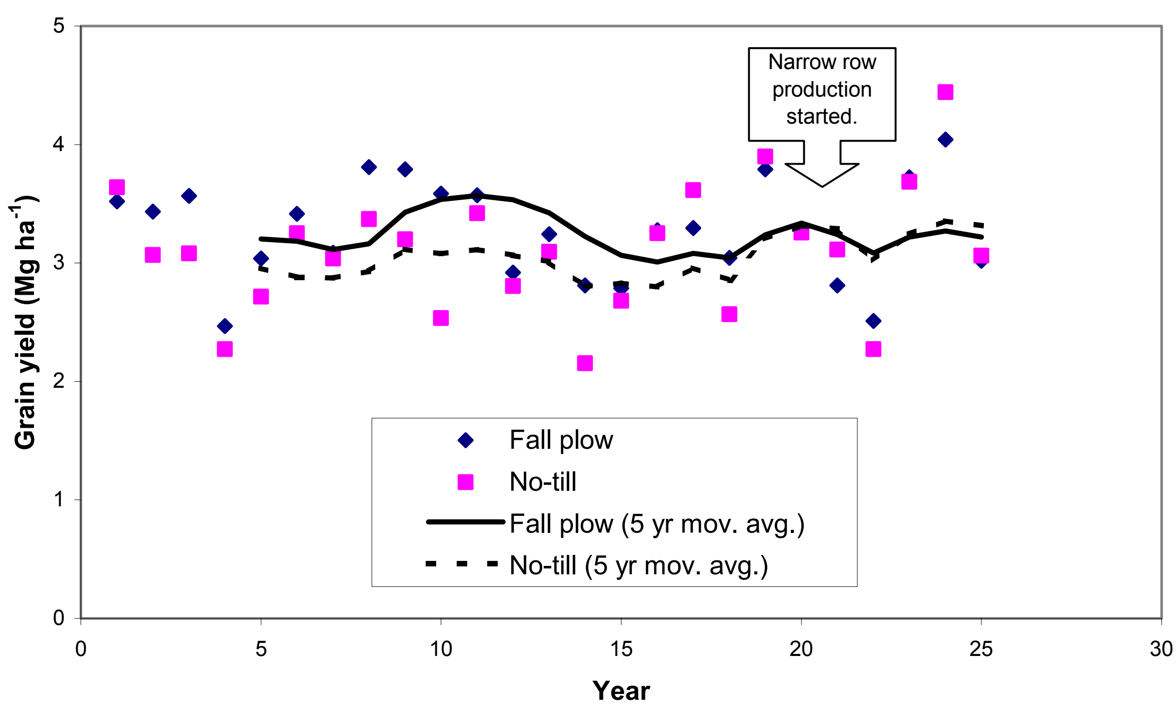

Fig. 4 Soybean yields after corn with plow versus no-till systems on Chalmers soil (1975-99).

Thus, despite maintaining high fertility levels, changing cultivars, increasing corn plant density, and adopting narrow row soybean production, overall yields appeared to have plateaued on this high organic matter prairie soil. Furthermore, conservation tillage adoption was not associated with a major upwards shift in this yield trend with time. The latter indicates that the relatively intensive adoption of no-till for soybean production has not caused any acceleration in overall soybean yields with time, at least not for level, dark prairie soils. Alternatively, one could argue that long-term no-till adoption is most likely to benefit crop yields on shallower, more erodible and lower organic matter soils.

CONCLUSIONS

Results from this study provide insight into the long-term effects of continuous conservation tillage adoption on corn and soybean yield response on the dark prairie soils of the Central and Northern Corn Belt. Although equipment cultivars and seeding rates were changed periodically, the tillage treatments themselves were not altered during the 25 yr period of this ongoing experiment.

The major conclusions regarding crop yields are:

1. Both corn and soybean yields were more than 10% greater in rotation than in continuous cropping when yield results were averaged over the four tillage systems.
2. The positive yield response to rotation was greatest for no-till corn (19%) and least for plowed corn (5%). In addition, the positive yield response to rotation was more consistent among tillage treatments for soybeans than for corn.
3. Corn yield reductions for no-till, relative to moldboard plowing, averaged 14% in continuous corn and just 3% in corn following soybeans. The extent of the yield reduction with no-till appears to have increased over the 25-yr period in continuous corn, but remained relatively stable with time for rotation corn.
4. Soybean yield reductions with no-till, relative to fall moldboard plowing, averaged 5% in both continuous soybeans and rotation soybeans. Tillage yield differences have decreased with time, and no-till yields have not been significantly lower than plow yields in the last 10 years.
5. Chisel plowing reduced corn yields by 3% and soybean yields by 5%, relative to moldboard plowing, only with continuous monoculture production.
6. Long-term trends indicate that neither corn or soybean yields are increasing with time despite the shifts to more modern cultivars as the experiment progressed.

Acknowledgements

Dr. Jerry V. Mannering, H. Galloway and Don R. Griffith initiated the experiment in 1975 and continued to coordinate research in this long-term site until their respective retirements in 1989, 1980, and 1995. Numerous faculty, research agronomists, and graduate students have been involved over the years in various multi disciplinary research investigations.

REFERENCES CITED

Adee, E.A., E.S. Oplinger, and C.R. Grau. 1994. Tillage, rotation sequence, and cultivar influences on Brown Stem Rot and soybean yield. J. Prod. Agric. 7:341-347.

Brown, H.J., R.M. Cruse, and T. Colvin. 1989. Tillage system effects on crop growth and production costs for a corn-soybean rotation. J. Prod. Agric. 2:273-270.

Chase, C.A., and M.D. Duffy. 1987. An economic analysis of the Nashua tillage study: 1978-1987. J. Prod. Agric. 4:91-98.

Christmas, E.P. 1994. Plant populations and seeding rates for no-till soybeans. AY-217. Purdue Univ. Coop. Ext. Serv., West Lafayette, IN.

CTIC, 1998. National crop residue management survey: 1998 results, CTIC, 1220 Potter Dr., West Lafayette, IN.

Dick, W.A., E.L. McCoy, W.M. Edwards, and R. Lal. 1991. Continuous application of no-tillage to Ohio soils. Agron. J. 83:65-73.

Dickey, E.C., J.P. Jasa, and R.D. Grisso. 1994. Long term tillage effects on grain yield and soil properties in a soybean/grain sorghum rotation. J. Prod. Agric. 7:465-470.

Gehring, D.A., G.C. Steinhardt, E.J. Kladivko, T.D. West, and T.J. Vyn. 2000. Soil physical property response to tillage and rotation on a dark prairie soil. In Proceedings of 15th Conference of the International Soil Tillage Research Organization (ISTRO). Fort Worth, TX (July 2-7).

Griffith, D.R., J. F. Moncrief, D.J. Eckert, J.B. Swan, and D.D. Brietbach. 1992. Influence of soil, climate, and residue on crop response to tillage systems. p. 25-33. In Conservation tillage system and management. Mid-west Plan Service, Iowa State Univ., Ames.

Griffith, D.R., E.J. Kladivko, J.V. Mannering, T.D. West, and S.D. Parsons. 1998. Long-term tillage and rotation effects on corn growth and yield on high and low organic matter, poorly drained soils. Agron. J. 80:599-605.

Hill, P.R. 1998. Use of rotational tillage for corn and soybean production in the Eastern Corn Belt. J. Prod. Agric. 11:125-128.

Janovicek, K.J., T.J. Vyn, and R.P. Voroney. 1997. No-till corn response to crop rotation and in-row residue placement. Agron. J. 89:588-596.

Kaspar, T.C., D.C. Erbach, and R.M. Cruse. 1990. Corn response to seed-row residue removal. Soil Sci. Soc. Am. J. 54:1112-1117.

Larney, F.J., and E.J. Kladivko. 1989. Soil strength properties under four tillage systems at three long-term study sites in Indiana. Soil Sci. Soc. Am. J. 53:1539-1545.

Mackay, A.D., E.J. Kladivko, D.R. Griffith, and S.A. Barber. 1985. Conservation tillage and corn root growth. Purdue Univ. Agric. Exp. Stn. Paper 10433.

Nakatsu, C.H., S.M. Brouder, J.D. Wilbur, F. Wanjau, and R.W. Doerge. 2000. Impact of tillage and crop rotation on corn development and its associated microbial community. In Proceedings of 15th Conference of the International Soil Tillage Research Organization (ISTRO). Fort Worth, TX (CD-ROM).

Opoku, G., T.J. Vyn, and C.J. Swanton. 1997. Modified no-till systems for corn following wheat on clay soils. Agron. J. 85:549-556.

Porter, P.M., J. Lauer, W.E. Lueschen, J.H. Ford, T.R. Hoverstad, E.S. Oplinger, and R.K. Crookston. 1997. Environment affects the corn and soybean rotation effect. Agron. J. 89:442-448.

Tiarks, A.E. 1977. Causes of increased corn root rot infection of continuous corn in no-tillage Hoytville clay loam in Northwestern Ohio. Ph.D. diss. Ohio State Univ., Columbus. (Diss. Abstr. 77:17145).

Vyn, T.J., G. Opoku, and C.J. Swanton. 1998. Residue management and minimum tillage systems for soybeans following wheat. Agron. J. 90:131-138.

West, T.D., D.R. Griffith, G.C. Steinhardt, E.J. Kladivko, and S.D. Parsons. 1996. Effect of tillage and rotation on agronomic performance of corn and soybeans: Twenty year study on dark silty clay loam soil. J. Prod. Agric. 9:241-248.

Yakle, G.A., and R.M. Cruse. 1984. Effects of fresh and decomposing corn plant residue extracts on corn seedling development. Soil Sci. Soc. Am. J. 48:1143-1146.