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Influence of Long-Term Tillage and Rotation Combinations on Crop Yields and Selected Soil Parameters
II. Results Obtained for a Typic Fragiudalf Soil

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Influence of Long-Term Tillage and Rotation Combinations on Crop Yields and Selected Soil Parameters. II. Results Obtained for a Typic Fragiudalf Soil

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INTRODUCTION

Conservation tillage practices were applied to about 30 percent of the total cropland of the United States in 1984 (3). No-till or zero tillage, a crop production system where tillage is limited to the opening of a slot for seed and fertilizer placement and weed control is accomplished entirely by herbicides, has experienced the greatest growth nationwide of any form of conservation tillage. No-tillage crop production increased approximately 20 percent, from 3.6 percent of the total cropland in 1983 to 4.4 percent in 1984. The increase in conservation tillage may be attributed primarily to the farmers' awareness that it is highly effective in controlling erosion (12) and that it reduces fuel and labor costs.

Experiments investigating the effects of various tillage and rotation combination treatments on crop yields were initiated in 1962 and 1963 at several locations in Ohio. With only slight modification, the same treatments have been continuously applied for more than 20 years. The original objectives of the experiments were to determine how much tillage was required to obtain satisfactory crop yields and how crop rotations and tillage interact to influence corn (*Zea mays* L.) yield.

Results obtained from evaluating the effect of continuous application of various tillage and rotation combination treatments on crop yield have been published for three different sites in Ohio through the 1983 crop year (8). Corn yields were positively influenced by no-tillage on the well-drained Wooster soil (Typic Fragiudalf), negatively influenced on the poorly drained Hoytville soil (Mollic Ochraqualf), and mixed on the somewhat poorly drained Crosby soil (Aeric Ochraqualf). Patterns of yield responses for soybean (*Glycine max* L.) and oats (*Avena sativa* L.) at the Wooster and Hoytville soil sites were similar to those observed for corn.

The continued application of the tillage and rotation treatments to various soil types also created changes in soil physical, chemical, and biological properties. Several changes have been reported for the Wooster and Hoytville sites (6,7). No-tillage resulted in significantly ($P = 0.05$) higher organic C, organic N, and soil enzyme activities in the 0 to 7.5-cm layer of both the Wooster and Hoytville soils than observed for the same layer under conventional tillage. The increased concentrations of these soil parameters were especially evident in the surface layer (0-1.25 cm) of the no-tillage soil. Below the 15-cm depth of the Hoytville soil, however, concentrations of the various soil parameters were generally lower under no-tillage when compared to conventional tillage. There was no effect of tillage below the 15-cm depth for the Wooster soil.

In addition to the crop yield and the soil chemical data, a large amount of other data have been collected during the tillage and rotation experiments since their initiation. This report is designed to collect data on crop growth and yield, and on soil physical, chemical, and biological properties that have been recorded at the Wooster site since 1962. A similar report (9) describes the Hoytville site. This comprehensive compilation of data has been undertaken to provide information to other researchers involved in conservation tillage studies.

MATERIALS AND METHODS

SITE CHARACTERISTICS

Soil and Drainage: The Wooster soil is a member of the fine, mixed, mesic family of Typic Fragiudalfs. Wooster soils consist of deep, well-drained, moderately slowly permeable soils on uplands. The soils are formed mainly in glacial till, although in some places the till is covered by a thin mantle of loess. The slope ranges from 2 to 18 percent. A typical cultivated soil profile consists of 0 to 15 cm silt loam of color dark grayish brown to light brownish gray with moderately fine to medium granular structure. The 15 to 25 cm layer is a light yellowish brown silt loam with weak to medium thin platy structure. The thickness of the solum ranges from 100 to 175 cm with the depth to the fragipan ranging from 50 to 90 cm. The content of coarse fragments is 2 to 20 percent above the B_{32x} horizon (0-69 cm) and 5 to 25 percent in the B_{3x} and C horizons. Below the plow layer the reaction ranges from very strongly acid to medium acid.

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Selected physical characteristics of the Wooster soil near the experimental site located at the OARDC in Wayne County, Ohio are listed in Table 1. The distribution of the Wooster soil series in Ohio is shown in Figure 1. Results obtained in this study are considered applicable to other Typic Fragiudalfs having similar climatic conditions.

Crop and Tillage History: The experimental site had been maintained as a grass meadow for 6 years prior to the initiation of the tillage and rotation combination experiment in 1962.

Climate: Mean monthly climatic conditions for the years of the experiment (1962-1984) are listed in Appendix Tables I and II.

EXPERIMENTAL DESIGN

Tillage Variables: (Applied to all grain crops in all rotations.):

1. Conventional Tillage (CT). Plowing was accomplished each spring with moldboard plow to a depth of 20 to 25 cm. Two or more 8 to 12 cm deep secondary tillage operations were applied in the spring prior to planting for seedbed preparation.

2. Minimum Tillage (MT). Plowing was accomplished each spring with a moldboard plow to a depth of 20 to 25 cm. No other tillage was applied prior to planting. On May 13, 1983 the MT plots for corn, soybeans, and oats were tilled using a paraplow to a depth of 35 cm. The paraplow is a tillage implement designed to loosen the subsurface soil layers while leaving the surface residue relatively undisturbed. In 1984 this treatment was converted to a NT treatment. The MT treatment represents 21 years of plow-plant, 1 year of paraplow, and 1 year of no-tillage.

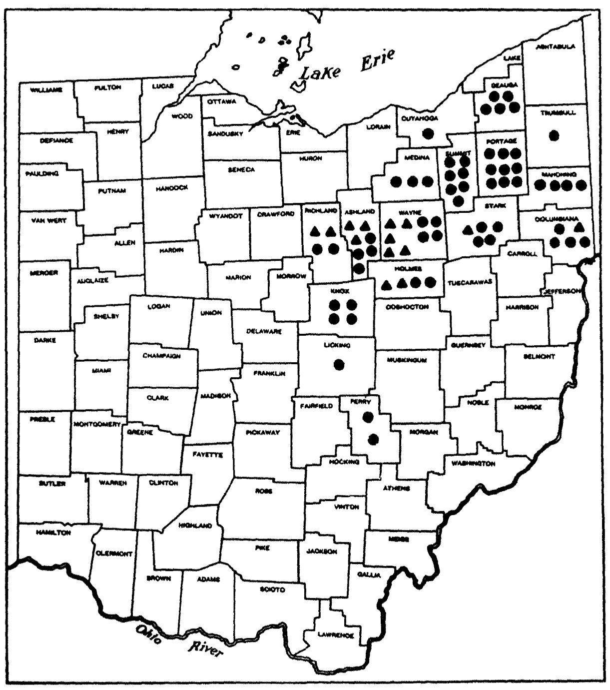

Figure 1. Distribution of the Wooster soil series in Ohio. Each solid circle represents 1,000 hectares and each solid triangle represents 10,000 hectares. The experimental site for which data is reported is located in Wayne Country.

3. No-tillage (NT). No tillage other than that accomplished with a coulter-type planter.

Rotation Variables:

1. Continuous corn (CC).

2. Corn-soybean in a 2-year rotation (CS). Every crop appeared in the experiment each year.

3. Corn-oats-meadow in a 3-year rotation (COM). Every crop appeared in the experiment each year. The meadow crop consisted of alfalfa (*Medicago sativa* L.) from 1962 to 1967, alfalfa-orchardgrass (*Dactylis glomerata* L.) mixture from 1968 to 1975, Kentucky 31 tall fescue (*Festuca arundinacea* Schreb) in 1976, and perennial ryegrass (*Lolium perenne* L.) from 1977 to 1984.

All combinations of the tillage and rotation variables gave nine treatments each year for corn and three treatments each for soybeans, oats, and meadow. The treatments were applied to the soil in a three-replication split-plot design with tillage being the whole plot and rotation applied to subplots. The treatment combinations were continued on the same plots, with the exception of the change in the MT treatment, from 1962 through 1984.

Management Practices:

1. Plot size. Plots were 22.3 m long and 4.3 m wide with the long dimension up and down the 2 to 4 percent slopes. Each plot of corn had 4 planted rows until 1973 when 6-row plots were started. Soybean plots had 4 rows through 1972, 6 rows from 1973 to 1976, and 12 rows from 1977 to 1984.

2. Fertilizer and Lime. Nitrogen was primarily added to the plots as ammonium nitrate which was broadcast in the spring prior to any tillage. From 1962 through 1967 P and K were applied in a band by the planter 5 cm below and 5 cm to the side of the seed. Beginning in 1966 P and K were broadcast applied in the spring. Lime was broadcast in the winter as required to maintain a pH of 6.0 in the A_p horizon of the continuous corn plots, but all other plots also received the same amount. A complete record of all the fertilizer and lime applications is provided in Appendix Table III.

3. Pesticides. Insecticides were applied primarily at planting time and primarily for corn. Herbicides were applied shortly after planting with follow-up spray applications made if further weed control

Table 1. Physical Characteristics of Wooster Silt Loam at Wooster, OARDC, in Wayne County, Ohio.†

Horizon	Horizon Depths	Core Depths	Organic Matter‡	Mechanical Analysis§			Moisture Retention#				Bulk Density
				Sand	Silt	Clay	0 bar	0.06 bar	0.33 bar	15 bar	
	cm		%				$100 \times m\ m^{-3}$				$Mg\ m^{-3}$
A_p	0-15	5-13	2.40	25	60	15	52.2	43.2	41.8	7.5	1.17
A_2	15-25	18-25	0.80	21	61	18	45.8	35.5	34.6	7.8	1.36
B_1	25-41	28-36	0.76	22	56	22	44.9	34.7	33.7	11.9	1.49
B_2	41-53	43-51	0.55	30	46	24	46.1	34.5	33.7	14.3	1.47
B_{31}	53-69	53-61	0.48	42	36	22	41.5	32.6	30.8	13.3	1.55
B_{32x}	69-97	79-86	0.48	40	37	23	-	-	-	15.5	1.69
B_{33x}	97-122	104-113	0.41	50	30	20	-	-	-	14.5	1.75
B_{34x}	122-147	132-140	0.62	24	47	29	39.5	34.2	33.5	15.8	1 71
C_1	147-168	155-163	0.48	58	27	15					
	168-183	173-180	0.48	59	25	16					
	183-216	196-203	0.28	69	20	11					
C_2	216-234	221-229	0.62	46	37	17					
	234-254	241-249	0.41	47	37	16					
	254-267	257-264	0.38	44	38	18					
	267-278	269-272	0.38	43	39	18					

† Data obtained by the Ohio State University Soil Survey Laboratory from a site within 250 m of the long-term tillage and rotation plots
‡ Determined by the Walkley-Black method as reported by reference (1)
§ Determined as reported in reference (5) for pipette analysis.
\# Determined during desorption of 7 5 cm long by 7 cm diameter "undisturbed" cylinders of soil as reported in reference (14) for 0 to 0 33 bar, and of disturbed samples as reported in reference (18) for 15 bar

measures were required. The greatest amounts of pesticides were applied to the corn and soybeans. Appendix Table IV provides a complete record of the pesticides applied and Appendix V lists the common and chemical names of the pesticides.

4. Planting, Thinning, and Harvest. All treatments for a given crop and year were planted to the same cultivar with the same planter on the same day. Cultivars of each crop were changed from time to time to take advantage of the better cultivars being released. Row spacing for corn was 102 cm from 1962 to 1972 and 76 cm from 1973 to 1984. Soybean row spacing decreased from 102 cm (1962-1972), to 76 cm (1973-1976), to 38 cm (1977-1984). Oats were seeded to rows spaced 18 cm apart for all years.

When corn plants were 0.2 to 0.5 m tall the emergent corn populations were recorded (Appendix Table VI) and the harvest area and the adjacent border rows were thinned to a common stand. Where plant populations for a specific plot were below a threshold level (which varied from year to year), no further thinning was done. Final corn populations were generally recorded in August after ear set was complete. Plant heights of corn and wilting ratings of corn were also determined periodically during the growing season.

Prior to harvest, the ends of the plots were trimmed and the harvest areas were measured. The harvest areas sometimes varied among treatments and years in order to achieve equal stand or weed control. Grain was harvested after drying in the field to moisture contents safe for storage. Corn yields were obtained by harvesting the center two rows. Soybean, oats, and hay yields were measured by cutting a swath of a known width from the center of each plot. Generally, all treatments of each crop each year were harvested on the same date. Planting and harvest dates for oats, soybeans, and corn are recorded in Appendix Table VII.

A moisture reading was obtained for each plot at harvest. Grain weights were calculated on the basis of 15.5 percent moisture for corn and 13.5 percent moisture for soybeans and oats. When hay yields were recorded, a wet sample was weighed in the field, brought to the laboratory, dried at 60°C, and reweighed to determine moisture content. A summary of corn grain yields and of soybean, oat, and hay yields is givin Appendix Tables VIII and IX. Individual corn and soybean plot yields which had weed growth causing severe competition and plots which exhibited a plant density below the threshold level were not included in the Appendix tables. Oat and hay plots were sometimes not included for similar reasons but the selection criteria were much less rigorous.

SOIL SAMPLING AND ANALYSIS

Soil samples (1.9-cm diameter soil cores) from a depth of 0 to 20 cm were collected in May 1967 and profile samples from 0 to 45 cm at 5 cm intervals were collected in October of 1971. The 1967 and 1971 samples were analyzed for pH, available P and available K by The Ohio State University soil and plant analysis laboratory. Bulk density measurements of each depth increment for the 1971 soil samples were calculated on a dry weight basis from total wet weight of sample corrected to zero moisture from gravimetric measurement of moisture content of a small subsample. Other chemical measurements performed on the 1971 soil samples (with the method reference given in parentheses) were organic C (1), organic N (6), exchangeable Ca, Mg, and K (2), cation exchange capacity (2), and pH (15).

Plots were sampled again in November of 1980 and soil profile samples (1.9-cm diameter soil cores) from 0 to 1.25 cm, 1.25 to 2.50 cm, 2.5 to 7.5 cm at 2.5-cm increments and from 7.5 to 30 cm at 7.5-cm increments from the NT plots and 0 to 30 cm at 7.5-cm increments from the MT and CT plots were collected. Samples were obtained after first removing from the soil surface easily identifiable plant materials, i.e., corn stalks and leaves. Exchangeable bases using ammonium as the exchange cation (2), organic C, N, and P (6), pH (15), available P (16), total phosphorus (6), and soil enzyme activities (7) were measured in the 1980 soil profile samples. Available and exchangeable K for the 1971 and 1980 samples represent the same data although the units are different when reporting available K versus exchangeable K.

The percentage of the soil covered by residues was determined for the no-tillage corn plots at 14 different sampling periods between 1963 and 1984. The residue cover values were determined by the point quadrat procedure (13).

Soil erosion as affected by tillage and rotation combination treatments were made from surface elevation data. After corn harvest in October 1971, a rectangular grid of surface elevation measurements, 16 per plot, was obtained using standard surveying equipment. Vertical measurements were made to the nearest 0.3 cm. The procedure was repeated in March 1976 and in April 1980 prior to spring tillage. Individual grid points were established as close as possible to the 1971 set. Elevations in tilled plots were compared with the average elevation of the no-till plots. A decrease in elevation of the tilled plots compared to the no-till plots was considered a measure of comparative soil erosion between the tillage treatments.

NUTRIENT COMPOSITION OF CORN

Ear leaves were collected at silking during eight growing seasons. The leaves were dried, ground, and analyzed for N, P, K, Ca, Mg, Fe, Zn, B, Cu, Sr, and Mo by The Ohio State University soil and plant analysis laboratory. A summary of the data is provided in Appendix Table X.

RESULTS AND DISCUSSION

Some of the data presented have been previously published, although without the great amount of supporting information that is given here. References to previously published data will be provided in the appropriate sections of this report.

CROP YIELDS

Grain yields of corn, soybeans, and oats as affected by the various tillage and rotation treatments applied to the Wooster silt loam soil are reported by Dick and Van Doren (8). Statistical analyses of yield data reported here were performed by the least squares method of Harvey (11) which utilizes data sets of unequal sizes. Only yields from plots that had similar plant populations at harvest and similar weed control for each crop year were included in the analyses.

Corn: Grain yields and plant emergence were summarized for the periods 1962-1973 (12 years), 1974-1984 (11 years), and for the entire 23-year observation period (Table 2). The data set was subdivided to separate results during the earlier years of the experiment when NT practices were not as well established. Yield increases of 1.09 and 1.19 Mg ha^{-1} from the 1962-1973 period to the 1974-1984 period were observed for the plowed (i.e., MT and CT) and no-tillage treatments, respectively. That the yields increased similarly indicates that increased additions of fertilizers, increased plant populations, and use of new crop cultivars had similar effects on corn grain yield under both NT and plowed treatments. An interaction effect was also evident. An increase in yield of 1.59 Mg ha^{-1} was observed, when the 1974-1984 period was compared to the 1962-1973 period, for the plowed treatments and COM rotation combinations. However, only a 0.40 Mg ha^{-1} increase was observed for the MT and CC combination treatment.

The influence of tillage on corn grain yield (Table 2) was significant (P=0.05). No-tillage practices produced an average of 0.84 Mg ha^{-1} more corn grain than did the plowed treatment over the 23-year observation period. Increased yields associated with NT on the Wooster soil is generally attributed to greater water use efficiency resulting from increased water infiltration, decreased evaporation, or both (19). In addition, the positive effect of NT on yield at the Wooster site may be due to decreased erosion, retention or development of favorable soil structural characteristics, and/or other unidentified factors. The potential for soil loss due to erosion is much less for NT than for the plowed treatments at the Wooster site (21). The retention of soil structural characteristics present in the meadow which existed for six years prior to the initiation of the tillage-rotation

Table 2. Corn Grain Yields and Initial Population of Plants as Affected by Various Tillage and Rotation Combinations.

Years	Rotation†	Tillage‡ NT	MT	CT	$LSD_{0.05}$§
		CORN GRAIN YIELD, Mg ha^{-1}			
1962-1973	CC	7.63	6.93	6.87	Tillage = 0.22
	CS	7 82	6.99	6.93	Rotation = 0.22
	COM	8.51	7.78	7.68	Til x Rot = 0.44
1974-1984	CC	8.74	7.33	7.73	Tillage = 0.29
	CS	8.91	8.08	7.98	Rotation = 0.29
	COM	9.88	9.36	9.27	Til x Rot = 0.57
1962-1984	CC	8 15	7.08	7.27	Tillage = 0.18
	CS	8.33	7.51	7.43	Rotation = 0.18
	COM	9.18	8.56	8.42	Til x Rot = 0.34
		INITIAL POPULATION, Thousands ha^{-1}			
1962-1973	CC	49.7	50.3	50.3	Tillage = 1.9
	CS	48.6	49.1	48.9	Rotation = 1.9
	COM	45.9	48.2	48.9	Til x Rot = 3.3
1974-1984	CC	60.0	60.1	61.5	Tillage = 2.3
	CS	55.5	57.4	57.0	Rotation = 2.3
	COM	55.9	58.9	56 5	Til x Rot = 4.3
1962-1984	CC	54.4	54.7	55.3	Tillage = 1.5
	CS	51.7	52.8	52.6	Rotation = 1.5
	COM	50.4	53.0	52.4	Til x Rot = 2.6

† CC, continuous corn, CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage, and CT, conventional tillage
§ The least significant difference values ($LSD_{0.05}$) were calculated by dividing the error mean square by the replicate number for the mean with the fewest observations

experiment may also have increased corn yields by maximizing infiltration (4).

Rotating soybeans with corn on a two-year rotation schedule (CS) did not significantly ($P=0.05$) affect corn yields when compared to the CC rotation (Table 2). However there was a significant increase in yield (1.06 Mg ha^{-1}) associated with the COM rotation when compared to the CC and CS rotations over the 23-year period. Continuous monoculture often results in lower yields when compared to the same crop being grown in rotation. Of particular interest is the fact that corn yields measured for the CS rotation were similar to those observed for CC rather than the COM rotation. The yield differences associated with tillage or rotation did not seem to be related to plant nutrition since similar nutrient concentrations were found in the ear leaf for all treatments (Appendix Table X). A more likely explanation for the lower than expected corn yields for the CS rotation is the decreased water content in the soil profiles of the CS rotation plots (Table 3). The lower yields associated with the CC when compared to the COM rotation, however, cannot be attributed to differences in soil water content and suggest that other factors may be interacting with tillage to affect yield. Work reported by Van Doren and Triplett (23) on a similar Wooster silt loam soil has shown that corn yields were greatest where soil was tilled and then a residue layer placed over the soil. A NT soil without residue cover or a tilled soil alone could not achieve the same yield as the combination of tillage and residue cover. These results suggest negative factors such as disease, that can be controlled by tillage, may need to be overcome before the full potential of the residue cover provided by NT can be realized. It is interesting to note that the three-year COM rotation, which would be expected to have the least disease pressures combined with the NT treatment, which provides residue cover, supported the highest corn yields of any treatment combination (Table 2).

The data recorded in Table 3 were obtained on July 1, 1971. Water content in the 0 to 15 cm and 15 to 30 cm soil increments were significantly ($P=0.05$) affected by tillage, rotation, and by the interaction effects of tillage and rotation. The treatment which resulted in the greatest soil water content in the 0 to 15 cm and 15 to 30 cm soil layers was the NT and COM combination treatment. Below the 30-cm depth there was no significant effect of tillage or rotation on the soil water content. Although Table 3 represents data for only a single sampling it does provide insight to explain the positive yield response of corn to NT. No-tillage provides available water to the corn crop for a longer period of time during the growing season. Greater water availability in the soil under NT during the critical pollination period could have a large effect on final yield.

Additional evidence for less water stress in the corn crop on plots where NT was applied is provided in Tables 4 and 5. Wilting ratings (Table 4) showed plants were not as stressed under NT when compared to the plowed treatments. The COM rotation treatment resulted in less water stress and lower wilting ratings when compared to the CC and CS rotations, although the COM rotation treatment was not as effective in reducing stress as the NT treatment. Plant heights of corn (Table 5) followed the same trend as that noted for the wilting ratings. Corn grown on the NT plots was often taller throughout

Table 3. Water Content in Soil Profiles as Affected by Tillage and Rotation (Measurements made 7/1/71).

Soil Depth	Tillage†	Water Content under Rotation Specified‡		
		CC	CS	COM
cm			%	
0-15	NT	20.6	16.7	23.3
	CT	14.9	14.0	15.4
15-30	NT	18.9	16.5	20.0
	CT	15.7	15.9	16.1
30-45	NT	17.9	16.9	18.7
	CT	15.8	15.9	15.8
45-60	NT	17.4	15.7	15.2
	CT	16.5	15.9	16.1
			STATISTICS ($LSD_{0.05}$)§	
		T	R	T by R
0-15		1.5	1.6	2.2
15-30		1.8	0.7	1.0
30-45		4.3	1.1	1.5
45-60		3.3	2.1	3.0

† NT, no-tillage; and CT, conventional tillage.
‡ CC, continuous corn; CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation
§ Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

the entire growing season. An additional observation was that the corn on the NT plots often began to tassel earlier (3 to 5 days) than the corn grown on the plowed plots. With greater moisture in the NT plots and the same planting date for all tillage treatments, one might expect the corn in the NT plots to be delayed in reaching silking.

Soybeans: Comparative yields for soybeans as affected by tillage under conditions of equal stand and weed control are summarized in Table 6. Greater yields were observed for the 1974-1983 period than the 1963-1973 periods. The yield increase was 0.21 for CT and 0.51 for the MT and NT treatments. The effect of tillage on soybean yields over the entire experimental period was significant (P=0.05) with yields for the NT treatment averaging 0.21 Mg ha^{-1} greater than for the plowed treatments. There was no significant difference in the average yield between the MT and CT treatment during the 1962-1983 period.

Oats and Hay: Less emphasis was placed on maintaining high oat and hay yields when compared to corn and soybean yields. The average oat yield for the 1962-1984 period was only 2.76 Mg ha^{-1} with a

Table 4. Wilting Ratings of Corn as Affected by Tillage and Rotation Combination Treatments.†

		NT‡			MT			CT			$LSD_{0.05}$††		
Year	Rating Date	CC§	CS	COM	CC	CS	COM	CC	CS	COM	T	R	T by R
1966	6/27	0	1.3	0	4.0	4.0	3.3	4.0	4.0	4.0	0.8	0.6	1.0
1971	6/23	0.7	2.0	0	2.5	2.5	1.8	4.0	3.5	2.5	2.3	0.6	1.1
	6/28	0.7	2.7	0	3.3	3.3	2.7	4.0	3.7	3.3	0.8	0.8	1.4
	7/7	2.5	3.5	1.0	5.0	5.0	3.5	5.0	5.0	3.5	0.4	0.3	0.5
1975	7/16	0	0	0	1.5	1.8	0.7	1.8	3.0	1.2	0.7	0.3	0.5
1978	7/21	0	0	—	3.2	2.8	1.0	2.7	3.3	1.0	0.8	0.5	0.9
	8/2	0	0	—	2.8	2.8	1.5	3.0	3.3	1.5	0.8	0.5	0.9
1981	8/26	0.3	0	0	4.3	3.0	3.7	4.0	4.3	2.3	0.6	0.8	1.4
1983	6/27	0	0	0	1.3	2.0	0	2.3	2.7	1.3	1.1	0.4	0.8
	7/21	0.3	0.5	0	2.5	3.7	0	3.5	4.3	1.3	0.8	0.2	0.4
	8/19	0.3	0.5	0	2.3	2.3	1.5	2.5	3.3	1.5	0.6	0.5	0.8

† Wilting ratings (0 = no wilting symptoms and 5 = severe symptoms).
§ CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
†† Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R). For the 1978 data, the COM results were not included in the analyses.

Table 5. Height of Corn as Affected by Various Tillage and Rotation Combination Treatments.†

		NT‡			MT			CT			$LSD_{0.05}$††		
Year	Measuring Date	CC§	CS	COM	CC	CS	COM	CC	CS	COM	T	R	T by R
		cm											
1967	8/15	191	200	198	176	160	173	183	180	191	11	13	23
1971	7/7	119	109	149	79	76	112	74	83	109	13	4	6
	7/20	217	208	261	142	141	210	144	140	208	25	7	12
1974	6/17	50	48	58	37	32	43	43	33	48	5	4	7
	6/27	72	73	83	53	45	67	60	50	67	10	5	7
	7/22	235	225	243	155	143	193	172	145	193	11	11	19
1975	7/14	237	233	212	160	147	173	157	123	147	24	18	31
1978	6/29	82	83	—	62	63	68	62	58	63	7	6	11
	7/10	142	148	—	112	112	127	105	108	120	18	13	22
	7/18	208	210	—	158	157	173	140	148	168	26	13	23
	7/25	258	265	—	202	205	220	187	192	220	18	13	22
1979	7/11	84	86	94	63	63	69	71	74	79	13	4	7
1981	6/24	80	84	82	61	60	67	63	59	68	8	4	7
	7/8	102	132	128	82	87	100	90	85	105	14	8	14
	8/20	305	309	316	268	283	283	272	276	289	13	9	16
1983	7/26	208	222	223	170	152	222	135	129	169	12	8	15
	8/19	300	305	315	250	240	310	230	215	265	26	10	17
1984	7/13	116	114	130	86	79	121	103	80	104	12	7	13
	9/5	266	270	285	246	242	277	234	234	251	7	9	16

† Standing height to nearest 5 cm.
§ CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
†† Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R). For the 1978 data, the COM rotation results were not included in the analyses.

slight decrease observed for the 1974-1984 period when compared to the 1962-1973 period (Table 7). Weed control and stand establishment were more often a problem for oats than for corn and soybeans. However, when plots with similar stand and weed control were compared, the NT treatment resulted in significantly (P=0.05) greater oat yields than in the plowed treatment. The average oat yield increase associated with NT was 0.21 Mg ha^{-1} over the total experimental observation period. The yield increase was attributed to greater water use efficiency under NT.

Hay yields (Table 8) were found to be negatively affected by no-till. Stand establishment was often a problem in the NT plots when compared to the plowed plots. Yields for all treatments were low.

Because of the lack of emphasis over the years to maintain high hay and oat yields, concrete conclusions of the effect of tillage on production of these two crops cannot be made. However, the data suggest oat yields may be positively influenced by no-tillage on a well-drained soil. To maintain equal hay yields under NT when compared to CT on the Wooster soil, emphasis must be placed on establishing a good stand.

SOIL MEASUREMENTS

Residue Cover: Plots on which NT practices were maintained demonstrated variable amounts of residue on the soil surface which, in turn, depended on the crop rotation (Table 9). The average residue cover value (70 percent) for the CC and the COM rotations were the same over the 14 years of observations. The CS rotation resulted in a significantly lower (P=0.05) amount of residue cover (44 percent). This observation is consistent with the fact that the CS rotation produces less residue than the other two rotations. However, even after the first year of the CS and NT combination treatment, sufficient residues (18 percent cover) were present to reduce erosion approximately 50 percent compared with CT practices. The data suggest that as the CS and NT combination treatment is continually applied to the Wooster soil, the percentage of ground covered by residue is increased. Between 1982 and 1984 the CS rotation had an average residue cover of 54 percent.

Soil Erosion Estimates: Erosion estimates made from surface elevation data indicate a significant (P=0.05) effect of tillage (Table 10). Decreased elevation of the tilled plots is assumed to be due to soil move-

Table 6. Soybean Grain Yields as Affected by Tillage.

	Tillage†			
Years	**NT**	**MT**	**CT**	**$LSD_{0.05}$‡**
	Mg ha^{-1}			
1963-1973	1.86	1.60	1.71	0.15
1974-1983	2.37	2.11	1.92	0.22
1963-1983	2.08	1.82	1.80	0.13

† NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
‡ The least significant difference values ($LSD_{0.05}$) were calculated by dividing the error mean square by the replicate number for the mean with the fewest observations.

Table 7. Oat Grain Yields as Affected by Tillage.

	Tillage†			
Years	**NT**	**MT**	**CT**	**$LSD_{0.05}$‡**
	Mg ha^{-1}			
1962-1973	2.98	2.76	2.74	0.25
1974-1984	2.75	2.55	2.56	0.20
1962-1984	2.87	2.66	2.65	0.17

† NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
‡ The least significant difference values ($LSD_{0.05}$) were calculated by dividing the error mean square by the replicate number for the mean with the fewest observations.

Table 8. Hay Yields as Affected by Tillage.

	Tillage†			
Years	**NT**	**MT**	**CT**	**$LSD_{0.05}$‡**
	Mg ha^{-1}			
1962-1973	7.57	7.71	8.15	0.50
1974-1984	6.16	7.08	7.17	0.58
1962-1984	6.83	7.37	7.64	0.39

† NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
‡ The least significant difference values ($LSD_{0.05}$) were calculated by dividing the error mean square by the replicate number for the mean with the fewest observations.

Table 9. Percentage of Soil Surface Covered by Residues in the No-tillage Corn Plots.

Year	Sampling Date	Soil Residue Cover for Rotation Specified† CC	CS	COM
			%	
1963	9/24	34	18	37
1964	7/3	57	79	60
1965	9/16	56	21	44
1966	8/18	87	54	75
1967	8/9	66	19	69
1968	9/10	92	76	92
1973	8/13	80	37	99
1974	8/6	72	41	39
1975	6/16	66	45	66
1978	6/27	60	37	93
1979	6/4	78	33	43
1982	5/26	77	57	88
1983	6/8	80	55	95
1984	6/22	79	50	82
Average ($LSD_{0\ 05}$ = 11)‡		70	44	70

† CC continuous corn CS, corn and soybeans in a two-year rotation, and COM corn, oats, and meadow in a three-year rotation
‡ The least significant difference value ($LSD_{0\ 05}$) was calculated by making each year equal to one replication and each tillage mean equal to one observation

Table 10. Soil Erosion Estimates from Reduction in Surface Elevations. The Mean of the No-tillage Treatment was Adjusted to Zero and the Other Tillage Treatments were Compared Relative to the No-tillage Treatment.

Years	Rotation†	Reduction in Surface Elevation as Affected by Tillage‡ NT	MT	CT
			cm	
1971-1976	CC	0 3	-1 2	1.5
	CS	-0 1§	0 2	2.6
	COM	-0 2	-0 4	2 4
	Mean	0	-0 5	2 2
$LSD_{0\ 05}$	Tillage = 1 3	Rotation = 1 3	Til x Rot = 2 2	
1971-1980	CC	0 2	1 5	3 6
	CS	0	2 5	4 3
	COM	-0 3	2 0	3 2
	Mean	0	2 0	3 7
$LSD_{0\ 05}$	Tillage = 1 4	Rotation = 1 4	Til x Rot = 2 4	

† CC, continuous corn, CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation
‡ NT, no-tillage, MT, minimum tillage, and CT, conventional tillage
§ A negative value indicates a higher surface elevation compared to the mean NT treatment

ment (erosion). Soil movement was assumed not to be due to tillage practices since the direction of tillage in a given year was always opposite that of the previous year. Bulk density measurements were not obtained but it was also assumed that the surface elevation differences with time were not associated with changes in degree of soil compaction. The surface elevation measurements were made after 10 years of continuous NT. The soil bulk densities would be well established and little change would be expected to occur with additional years of NT application.

The data in Table 10 indicate that sufficient erosion occurred between 1971 and 1976 to yield significant (P=0.05) difference in surface elevations between the CT and NT treatments Approximately 2.2 cm of soil was lost from the CT when compared to the NT treatment plots. The results for the MT treatment for this period were highly variable. After an additional four years (1971-1980 data), the effect of tillage on soil erosion estimates were more readily apparent. Both the MT and CT treatment plots had significantly lower surface elevations when compared to the NT treatment plots with the decrease in elevation measured being 2 0 and 3.7 cm, respectively. Assuming a bulk density of 1.30 Mg m^{-3}, a total of 260 and 480 Mg ha^{-1} more soil was lost from the MT and CT treatments, respectively, over the nine year period between 1971 and 1980. This indicates that on an annual basis an additional 29 and 53 Mg ha^{-1}

was lost from the MT and CT treatments when compared to the NT treatment. The slope at the experimental site ranges from 2.5 to 4.5 percent, with rows parallel to the slope. To the extent that such a large soil loss, approximately three times that predicted by the Universal Soil Loss Equation, seems excessive, the assumptions that tillage did not move soil downslope and that tilled plots had stable bulk densities may be false.

Soil Fertility: Soil samples were collected in the fall of 1967, 1971, and 1980. Available P, available K and pH were measured in the 1967 samples (Table 11). There was little effect of tillage noted in the 0 to 20 cm soil layer after the first five years of application of treatment. Available K was significantly (P=0.05) impacted by rotation with the COM rotation maintaining a lower level than the CC and CS rotations.

Surface application of fertilizers and deposition of plant residues on the soil surface creates a redistribution of nutrients in a NT as compared to a CT system. Therefore, when the plots were sampled again in the fall of 1971, samples were collected in 5-cm increments to more accurately determine the effect of NT on soil profile chemical properties. Soil pH was not affected by tillage but the soil under the CC rotation had a significantly (P=0.05) lower pH than that under the CS rotation to a depth of 20 cm (Table 12). The pH of the soil in the COM rotation plots was similar to that in the CS plots in the upper portion of the profile but significantly higher throughout the remainder of the soil profile. Available P concentrations were significantly higher in the 0 to 5 cm soil increment of the NT plots compared to the plowed plots. However, this effect only extended to a depth of 5 cm since there were no statistical (P=0.05) differences observed in the 5 to 10 cm soil increments. Between 10 to 25 cm, the NT plots exhibited significantly lower available P concentrations than the plowed plots. There was little effect of rotation on available P concentrations in the soil profiles. There was a less pronounced but similar (as P) pattern of tillage effect on available K concentrations. However, rotation did alter available K concentrations. The COM rotation exhibited significantly lower concentrations of K as compared to the CC and CS rotations. This is probably a reflection of the greater requirement of K by hay crops for growth and the subsequent removal of the cut hay from the plots.

In the fall of 1980 the plots were sampled for a third time and the effect of tillage and rotation on pH, available P, and available K observed in 1971 were even more evident (Table 13). Available P concentrations, for example, were approximately two times higher in the 0 to 7.5 cm soil layer of the NT plots compared to the plowed plots. At the soil surface (i.e., the 0 to 1.25 cm soil layer) available P concentrations were more than three times greater than in the plowed plots. This top soil layer has a very high capacity for supplying P to the plant and could be considered analogous to a horizontal fertilizer band. However, the contribution of this surface soil layer to plant nutrition may be greatly impacted by climate and biological (e.g., disease) activity restricting root growth near the soil's surface.

Available P and K concentrations in an approximate 0 to 20 cm soil layer, as affected by tillage, for the time periods of 1962, 1971, and 1980 are shown in Table 14. Comparisons of the data suggests that continued application of NT primarily affects nutrient distribution within the soil profile but not the total amount of nutrient available. The concentration of available P in the NT plots compared to the plowed plots was observed to be similar. For available K, however, concentrations in the NT plots were slightly less than in the plowed plots.

The effect of tillage on the redistribution of nutrients can be clearly ascertained by analyzing narrow soil layers as was done in 1971 and 1980. To confirm the observations concerning the total amount of nutrient in soil profiles as affected by tillage, samples must be collected from 0 to 20 cm in an identical manner at all sampling times.

Concentrations of exchangeable Ca, Mg, and K (1971 and 1980), exchangeable Mn (1980) and total P (1980) are shown in Tables 15 and 16. In the surface soil layers (approximately to a depth of 5 to 7.5

Table 11. pH, Available P and Available K in 0-20 cm Soil Samples (November, 1967).

	pH‡			Available P			Available K		
Rotation†	NT	MT	CT	NT	MT	CT	NT	MT	CT
				mg kg^{-1}					
CC	6.8	6.6	6.7	47	63	54	111	102	104
CS	7.0	6.6	6.8	47	74	55	98	119	106
COM	6.9	6.7	6.8	59	48	47	88	97	97
	STATISTICS ($LSD_{0.05}$)§								
	T	R	T by R	T	R	T by R	T	R	T by R
	0.2	0.2	0.3	6	5	9	6	10	18

† CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
§ Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

Table 12. Concentrations of Soil Fertility Parameters (October, 1971).

Rotation†	Soil Increment	pH‡			Available P			Available K			Exchangeable Bases§		
		NT	MT	CT	NT	MT	CT	NT	MT	CT	NT	MT	CT
					——————mg kg^{-1}——————						——cmol (+) kg^{-1}——		
CC	0-5	5.9	6.3	6.5	137	57	54	150	151	164	8.64	8.83	7.90
	5-10	6.0	6.3	6.6	56	54	50	110	131	123	7.32	7.99	7.44
	10-15	6.3	6.1	6.3	32	62	52	102	133	117	7.27	7.95	7.26
	15-20	6.3	6.1	6.1	21	44	35	92	116	104	7.33	8.95	7.40
	20-25	6.1	5.8	5.7	10	19	9	92	100	100	6.48	8.24	7.20
	25-30	5.7	5.4	5.2	5	6	3	90	97	95	6.20	8.45	7.13
	30-35	5.5	5.2	5.0	5	4	3	92	96	91	7.01	9.14	7.16
	35-40	5.5	5.1	5.0	5	3	2	99	101	97	7.50	9.51	7.52
	40-45	5.4	5.0	5.0	4	4	2	101	108	96	8.44	10.3	7.70
CS	0-5	6.4	6.5	6.7	126	73	49	209	158	143	10.5	9.04	8.64
	5-10	6.6	6.5	6.7	49	66	45	115	138	125	9.59	8.86	8.16
	10-15	6.6	6.3	6.5	29	61	47	86	143	132	8.72	8.59	7.90
	15-20	6.6	6.3	6.3	19	59	29	71	138	120	8.34	8.92	7.88
	20-25	6.2	6.0	5.7	9	27	12	75	116	101	7.48	8.37	7.21
	25-30	5.7	5.4	5.3	6	7	4	80	98	92	7.62	7.87	6.45
	30-35	5.3	5.1	5.2	4	4	3	89	92	88	8.21	7.82	7.14
	35-40	5.3	5.1	5.2	3	4	3	95	92	92	8.70	8.68	7.69
	40-45	5.3	5.1	5.2	3	4	3	100	91	91	9.40	9.47	8.08
COM	0-5	6.5	6.2	6.4	124	71	64	148	163	149	11.5	9.71	8.28
	5-10	6.6	6.4	6.6	53	58	50	80	92	88	10.4	9.49	8.57
	10-15	6.7	6.5	6.6	25	57	51	63	88	81	9.77	9.56	8.26
	15-20	6.6	6.5	6.5	20	43	38	57	78	77	9.38	9.47	7.90
	20-25	6.5	6.2	6.4	11	14	12	62	73	73	8.76	8.18	7.15
	25-30	6.0	5.7	5.9	6	8	6	74	72	70	8.75	7.86	6.78
	30-35	5.7	5.4	5.6	4	5	4	84	79	80	9.21	8.19	7.09
	35-40	5.5	5.3	5.5	3	4	3	93	87	87	10.0	8.40	7.85
	40-45	5.5	5.2	5.5	3	4	3	98	89	89	10.5	8.98	8.21
		——————STATISTICS ($LSD_{0.05}$) #——————											
		T	R	T by R	T	R	T by R	T	R	T by R	T	R	T by R
	0-5	0.3	0.2	0.3	21	11	19	24	37	64	2.36	0.75	1.31
	5-10	0.5	0.2	0.4	15	12	21	25	32	55	2.52	0.84	1.45
	10-15	0.4	0.2	0.3	14	8	13	26	38	66	2.60	0.73	1.27
	15-20	0.4	0.2	0.3	14	7	12	20	30	53	2.46	0.95	1.64
	20-25	0.5	0.3	0.4	14	10	17	14	21	37	2.09	0.77	1.34
	25-30	0.3	0.2	0.3	2.5	1.9	3.3	15	19	34	2.35	0.53	0.92
	30-35	0.2	0.2	0.4	0.8	0.9	1.5	11	14	24	1.76	0.74	1.29
	35-40	0.2	0.2	0.3	0.4	0.6	1.0	20	15	25	1.81	1.11	1.93
	40-45	0.2	0.2	0.3	1.0	0.6	1.1	23	12	20	2.07	0.92	1.59

† CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
§ Sum of exchangeable Ca, Mg, and K.
# Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

cm), chemical concentrations were higher in the NT plots than the plowed plots. From a depth of approximately 7.5 to 25 cm within the soil profile, the concentrations of parameters in the NT plots were lower. Below the 25 cm depth, most parameter concentrations were similar for the various tillage practices.

The redistribution of mineral nutrients in the soil profile brought about by tillage did not seem to have an impact on the nutrition of the corn crop. The concentrations of P and K in the ear leaf of corn plants obtained from the variously treated plots were found to be very similar (Appendix Table X).

Organic C, N, and P: The distribution of organic C, N, and P in soil profiles of the Wooster soil after 10 (sampled in 1971) and 19 (sampled in 1980) years of continuous application of the tillage and rotation combinations is shown in Tables 17 and 18. The data collected in 1980 have been previously reported (6). Comparison of concentrations of the organic parameters for the 1971 and 1980 sampling dates indicates that with time the plowed treatments caused a reduction in organic C and N levels. No-tillage, on the other hand, maintained organic C and N levels in the soil profile and similar levels were observed in 1971 and 1980.

Table 13. pH and Concentrations of Soil Fertility Parameters (November, 1980).

Rotation†	Soil Increment	pH‡ NT	pH‡ MT	pH‡ CT	Available P NT	Available P MT	Available P CT	Available K NT	Available K MT	Available K CT	Exchangeable Bases§ NT	Exchangeable Bases§ MT	Exchangeable Bases§ CT
	cm				mg kg^{-1}						cmol (+) kg^{-1}		
CC	0-1.25	7.1			166			271			14.9		
	1.25-2.5	7.0			161			189			12.9		
	2.5-5.0	6.9			107			138			10.3		
	5.0-7.5	6.8			61			111			9.0		
	0-7.5	(6.9)††	7.2	7.2	(111)	46	47	(160)	146	158	(11.1)	9.0	9.3
	7.5-15.0	6.9	7.2	7.2	28	42	47	84	131	137	8.0	9.0	9.1
	15.0-22.5	6.9	7.1	7.1	15	34	39	66	118	119	7.0	8.8	8.7
	22.5-30.0	6.8	6.5	6.6	8	9	6	79	106	93	6.5	7.9	6.8
CS	0-1.25	7.3			154			309			15.2		
	1.25-2.5	7.3			146			218			14.1		
	2.5-5.0	7.2			98			173			11.9		
	5.0-7.5	7.2			57			124			10.1		
	0-7.5	(7.2)	7.4	7.5	(102)	57	41	(187)	153	131	(12.2)	9.7	9.9
	7.5-15.0	7.2	7.3	7.5	29	57	41	105	140	115	8.9	9.7	9.8
	15.0-22.5	7.1	7.3	7.3	21	47	29	77	129	102	7.5	9.5	8.8
	22.5-30.0	6.7	6.8	6.5	6	9	5	75	98	79	6.9	7.5	7.1
COM	0-1.25	7.2			161			239			16.5		
	1.25-2.5	7.2			151			186			15.1		
	2.5-5.0	7.2			110			158			13.5		
	5.0-7.5	7.3			62			108			10.9		
	0-7.5	(7.2)	7.3	7.3	(109)	50	47	(160)	113	113	(13.4)	10.8	10.4
	7.5-15.0	7.3	7.3	7.3	28	48	43	67	105	99	9.3	10.6	10.4
	15.0-22.5	7.2	7.3	7.3	16	33	29	52	86	84	8.0	9.3	9.1
	22.5-30.0	7.0	7.1	7.0	9	10	7	59	79	74	7.2	7.6	7.3
		STATISTICS ($LSD_{0.05}$)#											
		T	R	T by R	T	R	T by R	T	R	T by R	T	R	T by R
	0-1.25		0.2			20			49			1.1	
	1.25-2.5		0.1			18			46			1.1	
	2.5-5.0		0.1			24			29			1.2	
	5.0-7.5		0.2			8			31			1.6	
	0-7.5	0.2	0.1	0.1	10	6	10	20	13	23	0.8	0.4	0.7
	7.5-15.0	0.2	0.1	0.2	11	3	5	12	15	27	0.5	0.7	1.3
	15.0-22.5	0.2	0.1	0.2	12	7	13	16	14	24	0.5	0.7	1 2
	22.5-30.0	0.3	0.2	0.3	3	3	5	16	11	19	1.0	0.5	0.9

† CC, continuous corn; CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage, and CT, conventional tillage.
§ Sum of exchangeable Ca, Mg, K, and Mn.
†† Calculated as a weighted average of the results obtained from the 0-1.25, 1.25-2.50, 2.5-5.0, and 5.0-7.5 cm soil increments.
# Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

Table 14. Comparison of Available P and K in the Wooster Soil Profile as Influenced by Tillage and Rotation for the Years 1967, 1971, and 1980†.

Rotation‡	Year	Available P§			Available K		
		NT	MT	CT	NT	MT	CT
		mg kg^{-1}					
CC	1967	47	63	54	111	102	104
	1971	63	54	48	114	133	127
	1980	51	41	44	103	132	138
CS	1967	47	74	56	98	119	106
	1971	56	64	43	114	137	130
	1980	51	54	37	123	141	116
COM	1967	59	48	46	88	97	97
	1971	56	57	51	87	109	109
	1980	51	44	40	93	101	99

† The 1967 data were obtained from 0-20 cm soil increment samples The 1971 and 1980 data were calculated from results reported in Tables 12 and 13, respectively and represent soil increments of 0-20 cm and 0-22 5 cm

‡ CC, continuous corn, CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation

§ NT, no-tillage, MT, minimum tillage, and CT, conventional tillage

Visual inspection of the surface soil layers clearly indicated a more aggregated and darker colored surface soil in the NT plots. Tillage operations stimulated the oxidation and decline of soil organic matter, a result of intensive cultivation practices that is well-known. Managing the soil so that the soil organic matter levels are maintained, instead of mineralized, is generally considered desirable. Organic matter serves as an aggregating material for soil particles, improving the soil physical properties, and providing a storehouse of plant nutrients. However, management of the carbon-enriched surface soil layer of the NT profiles must also take into account potential negative aspects such as immobilization of fertilizer nutrients and increased populations of disease organisms and insect pests.

Organic C concentrations were significantly impacted by the continuous application of various crop rotations (Tables 17 and 18), with the COM rotation having the highest concentration and the CS rotation the lowest. The difference in organic C concentrations as affected by rotation was especially evident in the NT plots and is directly related to the amount of total residue produced by the rotation (COM rotation produces the most residue and CS rotation the least). Organic N concentrations closely followed the pattern of organic C. However, the highest concentrations of organic P did not occur in the surface (0 to 1.25 cm) soil layer but at a depth of 5.0 to 7.5 cm. This suggests the possibility that organic P compounds may be moving downward into the soil profile. Pinck et al. (17) have shown that organic P compounds are more mobile in soil than inorganic P.

Table 17 also includes bulk density data obtained in the fall of 1971 after harvest was completed. There were no significant (P=0.05) differences in treatment means for tillage, rotation, or the interaction of tillage and rotation. Significant bulk density differences between the NT and CT treatments would be expected in the spring after plowing. However, after a single growing season the differences are no longer evident with only a trend towards increased bulk densities in the soil under NT being evident in the fall.

Enzyme Activities: Soil enzyme activities play an important role in the cycling of C, N, P and S and also have been used as indices of microbial activity in soil. Six soil enzymes were assayed in air-dried soil profile samples collected from the NT and CT corn plots. The results have been summarized in a previous publication (7), but a more complete description of the data is provided in Table 19. No-tillage significantly (P=0.05) increased enzyme activities in the surface soil layers (0 to 7.5 cm) but decreased activities in the lower profile layers (7.5 to 30.0 cm) as compared to CT. Rotation also greatly influenced activities with the COM rotation exhibiting the highest levels and the CS rotation the lowest. The activity of the soil enzymes were significantly (P=0.05) correlated with organic C concentrations.

Repeated applications of herbicides and insecticides on the NT plots without their incorporation by tillage operations to dilute their concentration throughout the soil profile did not seem to cause any adverse effects on soil enzyme activities. Instead, the activities of the various enzymes were found to be greatly amplified in the soil surface increment (0 to 1.25 cm) of the NT soil profiles because of the greater organic C concentrations which resulted from the maintenance of NT practices.

Enzyme activities may be used as indicators of microbial activity (10). The higher enzyme activities in the surface soil layers of the NT plots indicates greater biological activity has been established where NT practices have been maintained. High microbial activity is desirable for the decomposition of plant residues deposited on the soil surface so that the nutrients contained in the residue can be recycled. However undesirable effects of increased

Table 15. Concentrations of Exchangeable Ca, Mg, and K in Soil Profiles (October, 1971)†.

Rotation†	Soil Increment	Exchangeable Ca‡			Exchangeable Mg			Exchangeable K		
		NT	MT	CT	NT	MT	CT	NT	MT	CT
	cm	cmol (+) kg^{-1}								
CC	0-5	5.75	6.21	5.51	2.51	2.21	1.97	0.38	0.41	0.42
	5-10	5.26	5.70	5.36	1.78	1.95	1.77	0.28	0.34	0.31
	10-15	5.35	5.77	5.24	1.66	1.84	1.72	0.26	0.34	0.30
	15-20	5.31	6.44	5.29	1.78	2.21	1.84	0.24	0.30	0.27
	20-25	4.47	5.76	4.91	1.77	2.23	2.03	0.24	0.25	0.26
	25-30	4.10	5.71	4.75	1.87	2.49	2.14	0.23	0.25	0.24
	30-35	4.50	6.18	4.68	2.27	2.72	2.25	0.24	0.24	0.23
	35-40	4.83	6.40	4.80	2.42	2.85	2.47	0.25	0.26	0.25
	40-45	5.39	6.76	4.90	2.79	3.25	2.55	0.26	0.28	0.25
CS	0-5	7.19	6.39	6.05	2.78	2.24	2.22	0.55	0.41	0.37
	5-10	6.98	6.37	5.81	2.31	2.14	2.03	0.30	0.35	0.32
	10-15	6.65	6.19	5.61	1.84	2.03	1.95	0.23	0.37	0.34
	15-20	6.22	6.33	5.49	1.94	2.23	2.08	0.18	0.36	0.31
	20-25	5.32	5.89	4.91	1.97	2.23	2.04	0.19	0.25	0.26
	25-30	5.19	5.36	4.21	2.23	2.27	2.01	0.20	0.24	0.23
	30-35	5.58	5.20	4.61	2.40	2.38	2.30	0.23	0.24	0.23
	35-40	5.72	5.65	4.89	2.74	2.79	2.57	0.24	0.24	0 23
	40-45	6.03	6.05	5.05	3.12	3.18	2.80	0.25	0.24	0.23
COM	0-5	8.05	6.95	5.79	3.03	2.34	2.11	0.38	0.42	0.38
	5-10	7.60	6.92	6.17	2.55	2.33	2.17	0.21	0.24	0.23
	10-15	7.34	6.88	5.96	2.27	2.45	2.09	0.16	0.23	0.21
	15-20	6.99	6.87	5.62	2.25	2.39	2.04	0.14	0.21	0.24
	20-25	6.31	5.66	4.96	2.29	2.23	2.00	0.16	0.19	0.19
	25-30	6.06	5.31	4.54	2.50	2.36	2.06	0.19	0.19	0.18
	30-35	6.19	5.46	4.63	2.81	2.53	2.25	0.21	0.20	0.21
	35-40	6.58	5.53	5.01	3.18	2.65	2.62	0.24	0.22	0.22
	40-45	6.90	5.79	5.16	3.33	2.96	2.82	0.25	0.23	0.23
		STATISTICS (LSD$_{0.05}$)§								
		T	R	T by K	T	R	T by K	T	R	T by R
	0-5	1.87	0.60	1.05	0.55	0.22	0.39	0.04	0.04	0.07
	5-10	1.99	0.69	1.19	0.59	0.19	0.34	0.05	0.03	0.04
	10-15	2.05	0.59	1.03	0.60	0.19	0.33	0.05	0.03	0.05
	15-20	1.95	0.79	1.37	0.56	0.19	0.32	0.04	0.04	0.07
	20-25	1.64	0.66	1.14	0.47	0.13	0.23	0.03	0.03	0.05
	25-30	1.78	0.45	0.77	0.60	0.17	0.30	0.01	0.02	0.03
	30-35	1.45	0.54	0.93	0.38	0.28	0.49	0.03	0.02	0.03
	35-40	1.52	0.75	1.29	0.37	0.42	0.72	0.03	0.02	0.03
	40-45	1.66	0.59	1.02	0.49	0.38	0.66	0.03	0.02	0.04

† CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
§ Least significant difference values (LSD$_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction of tillage by rotation (T by R).

Table 16. Concentrations of Total P and Exchangeable Ca, Mg, Mn, and K in Soil Profiles (November, 1980).

Rotation†	Soil Increment	Total P‡ NT	Total P‡ MT	Total P‡ CT	Exchangeable Ca NT	Exchangeable Ca MT	Exchangeable Ca CT	Exchangeable Mg NT	Exchangeable Mg MT	Exchangeable Mg CT	Exchangeable Mn NT	Exchangeable Mn MT	Exchangeable Mn CT	Exchangeable K NT	Exchangeable K MT	Exchangeable K CT
	cm	mg kg^{-1}			cmol (+) kg^{-1}											
CC	0-1.25	987			9.3			4.6			0.26			0.69		
	1.25-2.5	977			8.1			4.1			0.21			0.48		
	2.5-5.0	859			6.5			3.3			0.17			0.35		
	5.0-7.5	741			5.8			2.8			0.15			0.28		
	0-7.5	(861)§	646	615	(7.0)	5.6	5.8	(3.5)	2.9	2.9	(0.19)	0.14	0.12	(0.41)	0.37	0.41
	7.5-15.0	644	648	639	5.3	5.6	5.8	2.4	2.9	2.9	0.11	0.11	0.11	0.22	0.34	0.35
	15.0-22.5	534	615	596	4.6	5.4	5.5	2.2	3.0	2.8	0.10	0.10	0.10	0.17	0.30	0.30
	22.5-30.0	442	477	407	4.1	4.6	4.0	2.1	2.9	2.5	0.07	0.08	0.06	0.20	0.27	0.24
CS	0-1.25	1030			9.5			4.6			0.26			0.79		
	1.25-2.5	931			9.1			4.2			0.20			0.56		
	2.5-5.0	820			7.7			3.6			0.15			0.44		
	5.0-7.5	717			6.6			3.1			0.12			0.32		
	0-7.5	(839)	720	681	(7.9)	6.0	6.2	(3.7)	3.2	3.2	(0.17)	0.12	0.11	(0.48)	0.39	0.34
	7.5-15.0	615	716	644	5.9	6.0	6.1	2.7	3.2	3.3	0.10	0.12	0.11	0.27	0.36	0.29
	15.0-22.5	497	665	553	5.0	5.8	5.3	2.2	3.2	3.2	0.08	0.11	0.09	0.20	0.33	0.26
	22.5-30.0	420	459	489	4.3	4.4	4.1	2.3	2.8	2.7	0.07	0.07	0.09	0.19	0.25	0.20
COM	0-1.25	1040			10.5			5.1			0.32			0.61		
	1.25-2.5	1020			9.7			4.7			0.26			0.48		
	2.5-5.0	913			8.6			4.3			0.20			0.40		
	5.0-7.5	755			6.9			3.5			0.16			0.28		
	0-7.5	(899)	746	663	(8.5)	6.8	6.7	(4.2)	3.6	3.3	(0.22)	0.16	0.16	(0.41)	0.29	0.29
	7.5-15.0	603	762	673	6.2	6.7	6.7	2.8	3.5	3.3	0.11	0.15	0.15	0.17	0.27	0.25
	15.0-22.5	528	669	590	5.3	5.8	5.7	2.5	3.2	3.1	0.10	0.11	0.10	0.13	0.22	0.22
	22.5-30.0	427	455	413	4.5	4.6	4.4	2.5	2.8	2.6	0.06	0.06	0.05	0.15	0 17	0.19
		STATISTICS ($LSD_{0.05}$)††														
		T	R	T by R	T	R	T by R	T	R	T by R	T	R	T by R	T	R	T by R
	0-1.25		136			0.9			0.4			0.04			0.13	
	1.25-2.5		124			0.9			0.5			0.04			0.12	
	2.5-5.0		98			1.1			0.2			0.04			0.07	
	5.0-7.5		61			1.1			0.5			0.02			0.08	
	0-7.5	117	38	66	0.7	0.4	0.6	0.2	0.2	0.2	0.02	0.01	0.02	0.05	0.03	0.06
	7.5-15.0	128	31	54	0.5	0.6	1.0	0.2	0.2	0.3	0.02	0.01	0.02	0.03	0.04	0.07
	15.0-22.5	75	28	48	0.4	0.5	0.9	0.2	0.2	0.3	0.01	0.01	0.02	0.04	0.04	0.06
	22.5-30.0	86	36	62	0.8	0.4	0.6	0.2	0.2	0.3	0.01	0.01	0.02	0.04	0.03	0.05

† CC, continuous corn; CS, corn and soybeans in a two-year rotation; COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
§ Calculated as a weighted average of the results obtained from the 0-1.25, 1.25-2.50, 2.5-5.0, and 5.0-7.5 cm soil increments.
†† Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

Table 17. Concentrations of Organic C and N and Bulk Density Measurements (October, 1971).

Rotation†	Soil Increment	Organic C‡			Organic N			Bulk Density		
		NT	MT	CT	NT	MT	CT	NT	MT	CT
	cm	%						$Mg\ m^{-3}$		
CC	0-5	2.16	1.36	1.28	0.168	0.108	0.107	1.38	1.34	1.20
	5-10	1.55	1.37	1.48	0.125	0.109	0.110	1.28	1.11	1.08
	10-15	1.38	1.35	1.51	0.096	0.110	0.111	1.29	1.26	1.33
	15-20	1.21	1.22	1.28	0.100	0.104	0.100	1.41	1.33	1.44
	20-25	0.61	0.66	0.68	0.079	0.066	0.069	1.50	1.49	1.59
	25-30	0.42	0.42	0.41	0.047	0.051	0.048	1.55	1.53	1.63
	30-35	0.38	0.35	0.35	0.047	0.045	0.044	1.56	1.55	1.62
	35-40	0.41	0.34	0.39	0.049	0.043	0.043	1.57	1.65	1.61
	40-45	0.37	0.36	0.38	0.047	0.044	0.043	1.56	1.52	1.65
CS	0-5	1.84	1.25	1.25	0.150	0.106	0.102	1.46	1.26	1.45
	5-10	1.55	1.25	1.28	0.130	0.104	0.103	1.32	1.12	1.24
	10-15	1.42	1.24	1.28	0.117	0.103	0.104	1.38	1.31	1.41
	15-20	1.01	1.13	0.99	0.091	0.098	0.085	1.43	1.42	1.49
	20-25	0.50	0.71	0.58	0.056	0.073	0.060	1.53	1.57	1.58
	25-30	0.44	0.40	0.36	0.050	0.050	0.047	1.54	1.66	1.66
	30-35	0.35	0.33	0.28	0.045	0.044	0.042	1.53	1.65	1.67
	35-40	0.32	0.30	0.28	0.042	0.042	0.041	1.60	1.71	1.65
	40-45	0.31	0.30	0.28	0.043	0.041	0.041	1.73	1.70	1.58
COM	0-5	2.30	1.69	1.66	0.187	0.141	0.135	1.37	1.35	1.38
	5-10	1.68	1.67	1.66	0.140	0.138	0.133	1.26	1.20	1.23
	10-15	1.44	1.60	1.60	0.120	0.136	0.129	1.36	1.34	1.37
	15-20	1.26	1.42	1.35	0.106	0.121	0.112	1.38	1.45	1.49
	20-25	0.63	0.70	0.70	0.063	0.070	0.063	1.49	1.59	1.55
	25-30	0.41	0.42	0.44	0.047	0.051	0.050	1.57	1.62	1.59
	30-35	0.39	0.39	0.38	0.045	0.047	0.046	1.55	1.64	1.59
	35-40	0.34	0.36	0.34	0.044	0.045	0.044	1.66	1.73	1.74
	40-45	0.36	0.34	0.33	0.045	0.045	0.043	1.68	1.67	1.71

STATISTICS ($LSD_{0.05}$)§

Soil Increment	T	R	T by R	T	R	T by R	T	R	T by R
0-5	0.08	0.12	0.21	0.010	0.005	0.009	0.36	0.17	0.30
5-10	0.17	0.08	0.14	0.009	0.003	0.005	0.12	0.07	0.13
10-15	0.18	0.09	0.15	0.015	0.012	0.020	0.09	0.08	0.13
15-20	0.20	0.14	0.25	0.020	0.009	0.015	0.06	0.07	0.12
20-25	0.25	0.09	0.16	0.024	0.013	0.023	0.11	0.07	0.12
25-30	0.13	0.08	0.14	0.006	0.002	0.004	0.06	0.07	0.12
30-35	0.07	0.08	0.14	0.005	0.002	0.003	0.09	0.05	0.09
35-40	0.07	0.09	0.15	0.003	0.003	0.005	0.11	0.08	0.14
40-45	0.04	0.06	0.11	0.003	0.003	0.004	0.16	0.08	0.15

† CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
§ Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

Table 18. Concentrations of Organic C, N, and P in Soil Profile Samples (November, 1980).

Rotation†	Soil Increment	Organic C‡ NT	Organic C‡ MT	Organic C‡ CT	Organic N NT	Organic N MT	Organic N CT	Organic P NT	Organic P MT	Organic P CT
	cm	%						mg kg^{-1}		
CC	0-1.25	2.66			0.220			155		
	1.25-2.5	2.17			0.180			174		
	2.5-5.0	1.61			0.151			196		
	5.0-7.5	1.37			0.116			225		
	0-7.5	(1.80)††	1.04	1.15	(0.156)	0.107	0.105	(195)	149	141
	7.5-15.0	1.13	1.04	1.16	0.112	0.103	0.103	222	184	166
	15.0-22.5	0.84	0.84	1.00	0.086	0.088	0.091	168	187	159
	22.5-30.0	0.42	0.45	0.38	0.052	0.062	0.051	114	148	119
CS	0-1.25	2.09			0.187			187		
	1.25-2.5	1.80			0.170			205		
	2.5-5.0	1.44			0.144			227		
	5.0-7.5	1.19			0.123			226		
	0-7.5	(1.53)	0.95	0.90	(0.149)	0.096	0.087	(216)	174	163
	7.5-15.0	1.08	0.92	0.92	0.109	0.095	0.091	231	153	152
	15.0-22.5	0.76	0.82	0.68	0.081	0.086	0.074	154	124	136
	22.5-30.0	0.30	0.32	0.33	0.050	0.052	0.050	104	66	119
COM	0-1.25	2.92			2.252			245		
	1.25-2.5	2.36			0.211			246		
	2.5-5.0	1.94			0.187			242		
	5.0-7.5	1.46			0.149			260		
	0-7.5	(2.01)	1.31	1.32	(0.189)	0.126	0.128	(249)	224	220
	7.5-15.0	1.10	1.34	1.37	0.117	0.135	0.124	215	257	219
	15.0-22.5	0.87	1.02	0.93	0.091	0.102	0.099	197	192	182
	22.5-30.0	0.37	0.39	0.39	0.052	0.056	0.056	110	116	96
		STATISTICS ($LSD_{0.05}$)#								
		T	R	T by R	T	R	T by R	T	R	T by R
	0-1.25		0.321			0.018			116	
	1.25-2.5		0.309			0.028			103	
	2.5-5.0		0.237			0.021			72	
	5.0-7.5		0.261			0.029			103	
	0-7.5	0.113	0.092	0.160	0.014	0.009	0.015	47	28	50
	7.5-15.0	0.105	0.076	0.131	0.014	0.010	0.018	55	37	65
	15.0-22.5	0.099	0.121	0.210	0.010	0.007	0.012	45	34	59
	22.5-30.0	0.092	0.080	0.138	0.004	0.005	0.009	23	32	53

† CC, continuous corn; CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
†† Calculated as a weighted average of the results obtained from the 0-1.25, 1.25-2.50, 2.5-5.0, and 5.0-7.5 cm soil increments.
# Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

Table 19. Activity of Soil Enzymes in Samples Collected from Plots Planted to Corn (November, 1980).

		Activity of Enzyme Specified‡											
	Soil	Alkaline Phosphatase§		Acid Phosphatase		Aryl-Sulfatase		Invertase		Amidase		Urease	
Rotation†	Increment	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	cm												
CC	0-1.25	196		300		116		413		24.3		466	
	1.25-2.5	98		267		81		197		18.7		276	
	2.5-5.0	61		199		73		125		21.0		148	
	5.0-7.5	41		151		59		72		13.5		85	
	0-7.5	(83)††	69	(211)	132	(77)	49	(167)	97	(18.7)	7.5	(201)	110
	7.5-15.0	58	75	136	117	52	43	55	102	8.0	6.0	59	102
	15.0-22.5	42	67	103	112	49	42	27	57	7.8	3.7	38	64
	22.5-30.0	18	53	94	67	19	17	26	16	2.7	3.3	30	33
CS	0-1.25	158		170		111		241		22.2		401	
	1.25-2.5	97		138		97		123		17.2		216	
	2.5-5.0	71		133		69		96		11.8		108	
	5.0-7.5	55		104		61		85		13.5		77	
	0-7.5	(85)	54	(130)	91	(78)	45	(121)	71	(15.0)	7.2	(165)	65
	7.5-15.0	49	64	96	88	45	36	56	73	8.6	5.7	45	71
	15.0-22.5	29	43	64	84	30	27	17	62	4.4	5.7	26	43
	22.5-30.0	29	47	65	78	17	10	20	20	2.1	3.3	13	16
COM	0-1.25	266		301		209		480		32.0		511	
	1.25-2.5	200		270		175		261		30.1		348	
	2.5-5.0	156		224		170		170		24.9		227	
	5.0-7.5	98		154		102		129		17.5		96	
	0-7.5	(162)	125	(221)	143	(155)	85	(223)	108	(24.5)	9.3	(251)	93
	7.5-15.0	56	105	105	135	74	78	67	129	9.7	8.4	62	134
	15.0-22.5	35	77	85	104	45	55	72	77	6.0	5.0	36	72
	22.5-30.0	25	44	64	87	15	22	14	21	3.4	2.7	14	20

STATISTICS ($LSD_{0.05}$)#

	T	R	T by R	T	R	T by R	T	R	T by R	T	R	T by R	T	R	T by R	T	R	T by R
0-1.25		90			58			67			92			7.8			155	
1.25-2.5		74			54			58			71			9.3			69	
2.5-5.0		40			58			38			42			9.9			87	
5.0-7.5		31			31			27			51			10.6			93	
0-7.5	39	22	32	44	24	34	4	17	24	34	37	53	1.7	5.0	7.1	68	25	35
7.5-15.0	24	31	44	51	10	14	8	24	34	47	46	65	3.5	4.3	6.0	8	21	30
15.0-22.5	37	17	25	59	23	33	16	16	22	20	25	35	5.9	2.2	3.2	35	21	30
22.5-30.0	25	25	35	22	23	32	9	9	12	18	16	23	2.4	2.5	3.5	35	12	17

† CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.

‡ Alkaline phosphatase, acid phosphatase, and arylsulfatase activities are expressed as μg of p-nitrophenol released g^{-1} soil h^{-1}; invertase activity as μg glucose released g^{-1} soil h^{-1}, amidase activity as μg NH_3-N released 3 g^{-1} soil $24h^{-1}$; and urease activity as μg of NH_3-N released g^{-1} soil $4h^{-1}$.

§ NT, no-tillage; and CT, conventional tillage.

†† Calculated as a weighted average of the results obtained from the 0-1.25, 1.25-2.50, 2.5-5.0, and 5.0-7.5 cm soil increments.

\# Least significant difference values ($LSD_{0.05}$) are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

biological activity must also be considered as it may increase soil and fertilizer N loss via denitrification and accelerate the decomposition of pesticides making weed and insect control more difficult. In addition, the increased urease activity at the surface of the NT plots may make it more difficult to design a N fertilizer management system that includes urea. The significance of increased soil enzyme activities in the upper portion of the soil profile where NT has been maintained on fertilizer management practices, weed control, and plant growth remains to be investigated.

SUMMARY

Few studies report long-term effects of various tillage and crop rotation combinations on crop yields and soil properties. All combinations of three tillage treatments (no-tillage (NT); minimum tillage or plow-plant (MT); and conventional tillage or plow-disk-plant (CT)) and of three rotations (continuous corn (CC); corn and soybeans in a 2-year rotation (CS); and corn, oats, and meadow in a 3-year rotation (COM)) were maintained on the same plots for 23 years, with all crops appearing each year. The soil was a sloping (2.5 to 4.5 percent) well-drained, Typic Fragiudalf. The original objective of the experiment was to determine the effect of tillage and rotation on crop yield when uniform stands of each crop within a year and uniform effective weed control were maintained. Crop yields were obtained each year and various soil measurements were made during the course of the experiment. The most extensive soil measurements were made after the 10th and 19th year of the experiment.

With similar plant densities and weed control, corn yields were significantly (P=0.05) greater where NT compared to CT practices were maintained. Over the 23-year period, corn grown by NT practices averaged 0.84 Mg ha^{-1} greater than where the plowed treatments were applied. Rotation also significantly affected corn yields with the COM rotation averaging 1.22 and 0.96 Mg ha^{-1} more than the CC and CS rotation, respectively. Wilting ratings of corn made during six growing seasons and soil moisture measurements made on July 1, 1971 indicated that increased water content in the soil profile, which is a result of the mulch layer on the surface of the NT plots, was the primary reason for the increased yields associated with NT. Similar observations were made for soybean and oat yields where NT yields, averaged over a 23-year period, were 0.27 and 0.21 Mg ha^{-1} greater, respectively, than the yields associated with the plowed treatments.

Residue cover measurements indicated that when corn followed soybeans in rotation a significantly (P=0.05) lower percentage of the soil was covered than when corn followed corn or hay. After the first year of growing corn in the CS rotation however, sufficient residues carried over from the corn year of the rotation to maintain residue covers of approximately 40 to 50 percent.

Soil measurements made after 10 and 19 years of application of the various tillage and rotation treatment combinations indicated a redistribution of hydrogen ions, organic matter, plant nutrients, and enzyme activities. The 0 to 7.5 soil layers of the NT plots were enriched in the above parameters when compared to the plowed treatments. However, the inverse was observed below the 7.5 soil profile depth. The effect of tillage generally became negligible below 25 cm. The differences in the distribution of soil parameters within the profile can be attributed to applying the majority of fertilizer as a broadcast application without mechanical incorporation for the NT treatment. In addition, for the NT treatment, nutrients taken up from the subsoil are incorporated into the plant and subsequently deposited on the soil surface as plant residue.

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APPENDIX

Table I. Mean Monthly Temperature Record.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	Mean Temperature During Month Indicated											
	°C											
1962	-4.6	-3.0	1.7	8.2	17.5	18.7	20.8	20.5	15.0	11.0	4.2	-5.4
1963	-7.7	-8.2	3.8	8.2	12.6	19.1	20.6	18.6	15.1	13.7	5.9	-6.6
1964	-1.8	-4.1	3.0	9.6	15.6	19.2	21.6	19.1	16.4	8.8	5.9	-0.3
1965	-3.4	-2.8	0.2	8.3	17.5	18.6	20.2	19.6	18.3	9.6	5.3	2.1
1966	-6.2	-2.1	3.9	7.9	11.8	19.8	22.7	20.4	15.7	9.1	5.0	-1.5
1967	-0.4	-4.8	2.7	9.7	11.4	21.2	20.7	19.4	14.9	11.2	2.1	0.4
1968	-6.2	-5.7	3.9	9.7	12.7	19.4	21.0	21.4	17.7	10.8	4.9	-2.4
1969	-3.9	-2.1	0.4	9.2	14.4	18.4	21.8	20.3	16.3	10.8	3.6	-3.9
1970	-7.5	-3.1	0.9	9.6	16.3	19.7	21.4	20.9	19.2	12.0	5.2	-0.2
1971	-5.6	-1.6	0.4	7.0	12.9	21.2	20.1	19.7	19.2	14.7	3.8	2.4
1972	-2.8	-3.8	1.5	7.9	15.1	16.7	21.1	19.7	17.1	8.7	3.6	0.8
1973	-1.7	-2.8	8.1	9.1	13.3	21.1	21.7	21.9	18.4	12.9	6.4	-0.1
1974	-0.7	-2.9	3.8	10.1	13.6	18.1	21.2	20.7	14.7	9.6	5.2	-1.3
1975	-0.8	-1.1	1.4	5.9	16.6	20.3	21.4	22.2	14.3	11.4	7.6	0.0
1976	-5.8	1.7	6.4	9.2	12.9	20.2	20.5	18.5	14.9	8.0	0.4	-5.6
1977	-12.1	-3.6	6.1	10.6	17.4	17.7	22.4	20.7	18.3	9.7	5.9	-2.5
1978	-7.9	-9.4	-0.2	7.9	13.9	19.3	20.3	20.9	18.8	9.2	5.7	-0.2
1979	-6.9	-8.5	5.3	7.9	13.5	19.1	20.5	20.4	16.9	10.4	5.5	0.6
1980	-3.1	-5.4	1.6	8.3	15.6	18.2	22.4	22.7	18.2	8.6	3.2	-2.6
1981	-6.9	-1.3	2.1	10.6	13.6	20.3	21.8	20.3	16.1	9.3	4.7	-1.8
1982	-7.5	-3.4	2.3	6.4	17.8	17.3	21.4	18.5	15.6	11.8	6.4	3.5
1983	-1.9	-0.1	4.6	7.8	12.7	19.6	22.7	22.6	17.6	11.3	5.8	-5.1
1984	-6.1	1.4	-2.0	8.5	12.4	20.8	20.3	20.9	15.6	13.3	3.9	2.4
23-yr. avg.	-4.8	-3.3	2.7	8.6	14.4	19.3	21.2	20.4	16.7	10.7	4.8	-1.2

Table II. Total Monthly Precipitation Record†.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	Precipitation During Month Indicated												
	mm												
1962	61	52	65	38	54	36	91	38	112	55	60	46	708
1963	32	20	123	75	66	63	90	54	18	8	38	22	609
1964	40	37	196	157	115	56	128	113	14	29	34	90	1009
1965	78	67	54	64	116	56	57	117	89	100	57	33	888
1966	56	55	43	93	69	43	56	88	52	33	132	56	776
1967	22	50	92	81	122	23	29	76	88	45	67	65	760
1968	102	5	58	46	184	91	54	88	71	36	95	68	898
1969	57	15	23	124	114	99	325	77	59	40	63	54	1050
1970	34	34	43	123	148	119	93	28	107	81	94	71	975
1971	33	72	56	20	84	49	110	12	83	33	37	92	681
1972	30	43	79	112	75	82	170	98	150	37	117	68	1061
1973	46	51	96	81	142	121	85	82	55	90	66	59	974
1974	75	38	116	70	109	64	18	142	53	35	107	90	917
1975	88	96	76	37	109	60	34	142	126	62	40	65	935
1976	70	71	72	37	50	93	88	110	66	66	12	23	758
1977	46	39	117	118	44	124	234	162	166	40	99	121	1310
1978	99	11	59	81	124	97	39	92	45	94	35	123	899
1979	66	68	35	105	100	93	64	127	217	41	71	46	1033
1980	36	29	111	73	94	130	146	236	41	44	45	42	1027
1981	9	75	21	115	92	135	84	54	93	44	52	59	833
1982	95	33	91	37	96	119	65	69	61	26	96	86	874
1983	29	25	53	128	119	58	111	38	62	90	124	65	902
1984	23	57	83	101	137	42	75	129	61	72	90	65	935
23-yr. avg.	53	45	77	83	103	81	98	94	82	52	71	66	905

† The weather reporting station was located within 1 km of the long-term tillage and rotation plots.

Table III. Lime and Fertilizer Rates Applied.

Rotation†	Year	Broadcast				Row		
		Lime	N	P_2O_5	K_2O	N	P_2O_5	K_2O
		$t\ ha^{-1}$	kg ha^{-1}					
CC	1962		168			11	45	45
	1963		168			11	45	45
	1964		168			11	45	45
	1965		168			11	45	45
	1966		168		118	11	45	45
	1967		168	112	112	11	45	45
	1968		235	47	114			
	1969	4.5	280	34	101			
	1970		280	56	123			
	1971		280	78	78			
	1972	2.3	280	45	45			
	1973	2.3	280	45	45			
	1974		280	67	200			
	1975		280	67	67			
	1976	2.3	280	67	67			
	1977		280	67	67			
	1978	3.4	280	67	67			
	1979		280	67	200			
	1980		280	70	200			
	1981		280	67	67			
	1982	4.5	375	116	320			
	1983		440	200	345			
	1984		333	87	168			
CS	1962		168(c)‡			11(c)	45(c,s)	45(c,s)
	1963		168(c)			11(c)	45(c,s)	45(c,s)
	1964		168(c)			11(c)	45(c,s)	45(c,s)
	1965		168(c)			11(c)	45(c,s)	45(c,s)
	1966		168(c)		118(c,s)	11(c)	45(c,s)	45(c,s)
	1967		168(c)	112(c,s)	112(c,s)	11(c)	45(c,s)	45(c,s)
	1968		235(c), 47(s)	47(c,s)	114(c,s)			
	1969	4.5	280(c)	34(c,s)	101(c), 34(s)			
	1970		280(c)	56(c,s)	123(c), 56(s)			
	1971		280(c)	78(c,s)	78(c,s)			
	1972	2.3	280(c)	45(c,s)	45(c,s)			
	1973	2.3	280(c)	45(c,s)	45(c,s)			
	1974		280(c)	67(c,s)	200(c,s)			
	1975		280(c)	67(c,s)	67(c,s)			
	1976	2.3	280(c)	67(c,s)	67(c,s)			
	1977		280(c)	67(c,s)	67(c,s)			
	1978	3.4	280(c)	67(c,s)	67(c,s)			
	1979		280(c)	67(c,s)	200(c,s)			
	1980		280(c)	79(c,s)	200(c,s)			
	1981		280(c)	67(c,s)	67(c,s)			
	1982	4.5	375(c)	116(c,s)	320(c,s)			

(Continued)

Table III. Lime and Fertilizer Rates Applied.
(Continued)

		Broadcast				Row		
Rotation†	**Year**	**Lime**	**N**	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
		$t\ ha^{-1}$			$kg\ ha^{-1}$			
CS	1983		440(c) ‡	200(c,s)	345(c,s)			
	1984		333(c)	87(c,s)	168(c,s)			
COM	1962		168(c)			11(c), 34(o)	45(c), 34(o)	45(c), 34(o)
	1963		168(c)			11(c), 34(o)	45(c), 34(o)	45(c), 34(o)
	1964		168(c)			11(c), 34(o)	45(c), 34(o)	45(c), 34(o)
	1965		168(c)			11(c), 34(o)	45(c), 34(o)	45(c), 34(o)
	1966		168(c)		118(c)	11(c), 34(o)	45(c), 34(o)	45(c), 34(o)
	1967		168(c)	112(c,o,m)	112(c,o,m)	11(c), 34(o)	45(c), 34(o)	45(c), 34(o)
	1968		235(c), 47(o,m)	47(c,o,m)	114(c,o,m)			
	1969	4.5	280(c), 56(o), 112(m)	34(c,o,m)	101(c), 34(o), 168(m)			
	1970		280(c), 75(o), 112(m)	56(c,o,m)	123(c), 56(o), 190(m)			
	1971		280(c), 75(o), 112(m)	78(c,om)	78(c,o), 212(m)			
	1972	2.3	280(c), 75(o), 112(m)	45(c,o,m)	45(c,o), 314(m)			
	1973	2.3	280(c), 112(m)	45(c,o,m)	45(c,o), 314(m)			
	1974		280(c), 75(o)	67(c,o,m)	200(c,o), 334(m)			
	1975		280(c), 75(o)	67(c,o,m)	67(c,o), 200(m)			
	1976	2.3	280(c), 75(o), 112(m)	67(c,o,m)	67(c,o), 200(m)			
	1977		280(c), 75(o)	67(c,o,m)	67(c,o,m)			
	1978	3.4	280(c), 75(o)	67(c,o,m)	67(c,o,m)			
	1979		280(c), 75(o), 150(m)	67(c,o,m)	200(c,o,m)			
	1980		280(c), 75(o), 150(m)	70(c,o,m)	200(c,o,m)			
	1981		280(c), 75(o), 150(m)	67(c,o,m)	67(c,o,m)			
	1982	3.4	375(c), 75(o,m)	116(c,o,m)	320(c,o,m)			
	1983		440(c), 75(o,m)	200(c,o,m)	345(c,o,m)			
	1984		333(c), 74(o,m)	87(c,o,m)	168(c,o,m)			

† CC, continuous corn; CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation
‡ The lower case letter in parenthesis indicates the crop within the rotation to which the fertilizer and/or lime was applied

Table IV. Herbicide and Insecticide Materials and Rates Applied.

Rotation†	Year	Herbicide and Insecticide Applied to Tillage System Specified‡		
		No-Tillage	Minimum Tillage	Conventional Tillage
		kg active ingredients ha^{-1}		
CC	1962	3.4-At, 4.5-AmT	3.4-At	same as MT
	1963	3.4-At, 2.2-AmT	3.4-At	same as MT
	1964	3.4-At, 3.4-AmT	same as NT	same as NT
	1965	3.4-At, 3.4-AmT	same as NT	same as NT
	1966	3.4-At, 3.4-AmT	same as NT	same as NT
	1967	0.6-P, 1.1-At, 0.6-Ban, 1.7-Lox	same as NT	same as NT
	1968	0.6-P, 1.1-At, 0.6-Ban, 1.7-Lox, 3.4-Cl	same as NT	same as NT
	1969	0.6-P, 1.1-At, 0.6-Ban, 1.1-Lox, 1.1-Sim, 3.4-Cl	same as NT	same as NT
	1970	0.6-P, 1.1-At, 0.6-Ban, 1.1-Lox, 1.1-Sim, 3.4-Cl	same as NT	same as NT
	1971	0.6-P, 1.1-At, 0.6-Ban, 1.1-Sim, 2.2-Las, 3.4-Cl	same as NT	same as NT
	1972	0.6-P, 1.1-At, 0.6-Ban, 1.1-Sim, 2.2-Las, 1.1-F, 1.1-2,4-D	same as NT minus 1.1-2,4-D	same as NT
	1973	0.6-P, 1.1-At, 0.6-Ban, 1.1-Sim, 2.2-Las, 1.1-F	same as NT	same as NT
	1974	1.1-At, 0.6-Ban, 1.1-Sim, 3.4-Las, 1.1-R, 1.1-F	same as NT	same as NT
	1975	1.1-At, 0.6-Ban, 1.1-Sim, 3.4-Las, 1.1-R, 1.1-F	same as NT	same as NT
	1976	1.1-At, 0.6-Ban, 1.1-Sim, 3.4-Las, 1.1-R, 1.1-F	same as NT	same as NT
	1977	1.1-At, 0.6-Ban, 1.1-Sim, 3.4-Las, 1.1-R, 1.1-F	same as NT	same as NT
	1978	1.1-At, 0.6-Ban, 1.1-Sim, 3.4-Las, 1.1-R, 1.1-F	same as NT	same as NT
	1979	1.1-At, 0.6-Ban, 1.1-Sim, 3.4-Las, 1.1-R, 1.1-F	same as NT	same as NT
	1980	1.7-Sim, 1.1-R, 2.8-Bl, 1.1-F	same as NT	same as NT
	1981	2.2-Sim, 1.1-R, 2.2-Bl, 1.1-C	same as NT	same as NT
	1982	2.2-Sim, 2.2-Bl, 1.1-R, 1.1-C	same as NT	same as NT
	1983	0.6-P, 3.3-Bl, 3.3-Du, 0.3-Ban, 1.1-C	same as NT	same as NT
	1984	1.1-P, 2.2-Bl, 3.3-Du, 0.3-Ban, 1.1-C, 2.2-Sev	same as NT	same as NT
CS	1962	3.4-At(c)§, 4.5-AmT(c,s), 3.4-Am(s)	3.4-At(c), 3.4-Am(s)	same as MT
	1963	3.4-At(c), 2.2-AmT(c,s), 3.4-Am(s)	3.4-At(c), 3.4-Am(s)	same as MT
	1964	3.4-At(c), 3.4-AmT(c,s), 4.5-Am(s)	3.4-At(c), 3.4-AmT(c), 4.5-Am(s)	same as MT
	1965	3.4-At(c), 3.4-AmT(c,s), 4.5-Am(s)	3.4-At(c), 3.4-AmT(c), 4.5-Am(s)	same as MT
	1966	3.4-At(c), 3.4-AmT(c,s), 4.5-Am(s)	3.4-At(c), 3.4-AmT(c), 4.5-Am(s)	same as MT
	1967	corn as for CC, 3.4-Am(s), 3.4-AmT(s), 1.1-Lox(s)	same as NT	same as NT
	1968	corn as for CC, 3.4-Am(s), 3.4-AmT(s), 1.1-Lox(s)	same as NT	same as NT
	1969	corn at 2/3 rate as CC plus 1.1-2, 4-D, 3.4-Cl, 3.4-Am(s), 1.1-Lox(s)	corn as NT minus 1.1-2,4-D, soybeans as NT	same as MT
	1970	corn at 2/3 rate as CC plus 1.1-2,4-D(c), 3.4-Cl, 3.4-Am(s), 1.1-Lox(s), 0.6-P(s)	corn as NT minus 1.1-2,4-D, soybeans as NT	same as MT
	1971	corn at 2/3 rate as CC plus 1.1-2,4-D(c), 3.4-Cl(c), 1.1-Lox(s), 2.2-Las(s), 0.6-P(s)	corn as NT minus 1.1-2,4-D, soybeans as NT	same as MT
	1972	corn at 2/3 rate as CC, 1.1-F(c), 1.1-Lox(s), 2.2-Las(s), 1.1-Sev(s)	corn as NT minus 1.1-2,4-D, soybeans as NT	same as MT
	1973	corn at 2/3 rate as CC, 1.1-F(c), 2.2-Lox(s), 2.2-Las(s)	corn as NT, soybeans as NT minus 2.2-Mon(s)	same as MT
	1974	corn at 2/3 rate as CC, 1.1-F(c), 1.1-Lox(s), 2.2-Las(s), 2.2-R(s)	same as NT	same as NT
	1975	corn at 2/3 rate as CC, 1.1-F(c), 0.6-Sen(s), 3.4-Las(s), 2.2-R(s)	corn as NT, soybeans at 2/3 rate as NT	same as MT
	1976	corn at 2/3 rate as CC, 1.1-F(c), 0.6-Sen(s), 3.4-Las(s), 2.2-R(s)	corn as NT, soybeans at 2/3 rate as NT	same as MT
	1977	corn at 2/3 rate as CC, 1.1-F(c), 0.6-Sen(s), 3.4-Las(s), 3.3-R(s)	corn as NT, soybeans at 2/3 rate as NT	same as MT
	1978	corn at 2/3 rate as CC, 1.1-F(c), 0.6-B(s), 2.2-H(s), 0.4-G(s), 1.1-R(s)	corn as NT, soybeans as NT minus 0.6-B	same as MT
	1979	corn at 2/3 rate as CC, 1.1-F(c), 0.4-G(s), 3.4-Las(s), 2.2-R(s)	corn as NT, soybeans at 2/3 rate as NT	same as MT
	1980	corn at 2/3 rate as CC, 1.1-F(c), 0.6-Sen(s), 1.1-R(s), 1.4-Sf(s)	same as NT	same as NT
	1981	corn at 2/3 rate as CC, 1.1-C(c), 1.1-R(s), 0.6-Sen(s), 1.3-Sf(s)	same as NT	same as NT

(Continued)

Table IV. Herbicide and Insecticide Materials and Rates Applied.
(Continued)

		Herbicide and Insecticide Applied to Tillage System Specified‡		
Rotation†	**Year**	**No-Tillage**	**Minimum Tillage**	**Conventional Tillage**
		— kg active ingredients ha^{-1} —		
CS	1982	corn at 2/3 rate as CC, 1.1-C(c),§ 1.1-R(s), 0.6-Sen(s), 0.3-Sf(s)	same as NT	same as NT
	1983	corn at 2/3 rate as CC plus 2.2-R(c), 1.1-R(s), 0.6-Sen(s), 0.3-Sf(s), 1.1-Sev(s)	same as NT	same as NT
	1984	corn as for CC, 1.1-R(s), 0.6-Sen(s), 0.3-Sf(s), 1.1-R(s), 0.3-Bas(s)	same as NT	same as NT
COM	1962	3.4-At(c), 4.5-AmT(c)	3.4-At(c)	same as MT
	1963	3.4-At(c), 2.2-AmT(c)	3.4-At(c)	same as MT
	1964	3.4-At(c), 4.5-AmT(c), 1.1-Sim(c)	3.4-At(c), 3.4-AmT(c)	same as MT
	1965	3.4-At(c), 4.5-AmT(c), 1.1-Sim(c)	3.4-At(c), 3.4-AmT(c)	same as MT
	1966	3.4-At(c), 4.5-AmT(c), 1.1-Sim(c)	3.4-At(c), 3.4-AmT(c)	same as MT
	1967	corn same as for CC	same as NT	same as NT
	1968	corn same as for CC	same as NT	same as NT
	1969	corn as for CC plus 1.1-2,4-D(c)	corn same as for CC	same as MT
	1970	corn as for CC plus 1.1-2,4-D(c)	corn same as for CC	same as MT
	1971	corn as for CC plus 1.1-2,4-D(c)	corn same as for CC	same as MT
	1972	corn as for CC	corn same as for CC	same as MT
	1973	corn as for CC plus 1.1-At(c)	corn same as for CC	same as MT
	1974	corn as for CC plus 1.1-R(c) and 1.1-At(c), 1.1-R(m)	corn same as for CC, 1.1-R(m)	same as MT
	1975	corn as for CC, 1.1-R(o)	corn same as for CC	same as MT
	1976	corn as for CC plus 4.5-At(c) and 1.1-R(c), 2.2-R(o), 2.2-Sev(m)	corn same as for CC, 2.2-R(o), 2.2-Sev(m)	same as MT
	1977	corn as for CC plus 4.5-At(c) and 1.1-R(c), 1.1-R(o)	corn same as for CC	same as MT
	1978	corn as for CC plus 5.6-At(c) and 1.1-R(c), 2.2-R(o)	corn same as for CC	same as MT
	1979	corn as for CC plus 4.5-At(c) and 1.1-R(c), 2.2-R(o)	corn same as for CC, 1.1-R(o)	same as MT
	1980	corn as for CC plus 4.5-At(c) and 2-R(c,o)	corn same as for CC, 1.1-R(o)	same as MT
	1981	corn as for CC plus 1.1-R(c), 2.2-R(o)	corn same as for CC, 2.2-R(o)	same as MT
	1982	corn as for CC plus 3.3-R(c) and 4.5-At(c), 2.2-R(o)	corn same as for CC, 2.2-R(o)	same as MT
	1983	corn as for CC plus 2.2-R(c), 2.2-R(o), 1.1-Bas(o)	corn same as for CC, 2.2-R(o), 1.1-Bas(o)	same as MT
	1984	corn as for CC, 3.3-R(o)	corn same as for CC, 3.3-R(o)	same as MT

† CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ The herbicides and insecticides are coded for by the following letters (see following table (Table V) for chemical names).

Am = Amiben	Bl = Bladex	F = Furadan	P = Paraquat	2,4-D = 2,4-D amine
AmT = Aminotriazole	Cl = Chlordane	G = Goal	R = Roundup	Sim = Simazine
At = Atrazine	C = Counter	H = Hoelon	Sen = Sencor	
Ban = Banvel	D = Dalapon	Las = Lasso	Sev = Sevin	
Bas = Basagran	Du = Dual	Lox = Lorox	Sf = Surflan	

§ The lower case letter in parentheses indicates the crop within the rotation to which the pesticide was applied.

Table V. Trade (Common) and Chemical Names of Herbicide and Insecticide Materials Used in the Long-Term Tillage and Rotation Experiment.

Trade Name or Common Name	Chemical Name
Herbicides:	
Amiben (chloramben)	3-amino-2,5-dichlorobenzoic acid
Amitrole	1*H*-1,2,4-triazol-3-amine
Atrazine	6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine
Banvel (dicamba)	3,6-dichloro-2-methoxybenzoic acid
Basagran (bentazon)	3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2, 2-dioxide
Bladex (cyanazine)	2-((4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl)amino)-2-methylpropanenitrile
Dalapon	2,2-dichloropropanoic acid
Dual (metolachlor)	2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide
Goal (oxyfluorfen)	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene
Hoelon (diclofop methyl)	(±)-2-[4-(2-4-dichlorphenoxy)-phenoxyl] methyl propanoic acid
Lasso (alachlor)	2-chloro-*N*-(2, 6-diethylphenyl)-*N*-(methoxymethyl) acetamide
Lorox (linuron)	*N'*-(3, 4-dichlorophenyl-*N*-methoxy-*N*-methylurea
Paraquat	1,1'-dimethyl-4,4'-bipyridinium ion
Roundup (glyphosphate)	*N*-(phosphonomethyl) glycine
Simazine	6-chloro-*N*,*N'*-diethyl-1,3,5-triazine-2,4-diamine
Sencor (metribuzin)	4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one
Surflan (oryzalin)	3,5-dinitro-N^4, N^4-dipropylsulfanilamide
2,4-D	2,4-dichlorophenoxy acetic acid
Insecticides:	
Chlordane	1,2,4,5,6,7,8,8-octachlor-2,3,3a,4,7,7a-hexahydro-4,7-methanoindane
Counter (terbufos)	*S*-(((1,1-dimethylethyl)thio)methyl)*0,0*-diethyl phosphorodithioate
Furadan (carbofuran)	2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate
Sevin (carbaryl)	1-naphthyl *N*-methylcarbamate

Table VI. Emergence of Corn as Affected by Tillage.

Year	Rotation†	Plant Population After Emergence and Prior to Thinning‡		
		NT	MT	CT
		thousands ha^{-1}		
1962	CC	28.9	43.2	49.7
	CS	33.3	43.4	51.4
	COM	37.7	42.4	49.5
1963	CC	35.5	35.9	45.6
	CS	33.2	32.3	47.1
	COM	27.7	37.9	43.3
1964	CC	82.9	43.4	53.6
	CS	67.1	46.0	48.6
	COM	76.9	45.3	50.5
1965	CC	31.9	47.3	30.0
	CS	27.7	43.5	29.8
	COM	32.8	44.1	30.0
1966	CC	51.6	42.1	52.9
	CS	52.8	44.7	50.9
	COM	51.4	40.8	47.4
1967	CC	43.0	45.8	44.5
	CS	37.5	41.5	40.2
	COM	35.1	44.0	42.2

(Continued)

† CC continuous corn CS corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation
‡ NT, no-tillage, MT, minimum tillage, and CT conventional tillage

Table VI. Emergence of Corn as Affected by Tillage.
(Continued).

Year	Rotation†	Plant Population After Emergence and Prior to Thinning‡		
		NT	MT	CT
		————thousands ha^{-1}————		
1968	CC	65.8	67.3	65 6
	CS	63.3	67.2	65 8
	COM	65 7	64.0	61 9
1969	CC	41.9	55.1	49 1
	CS	47.8	55 1	51.8
	COM	47.0	50.4	55 2
1970	CC	28 7	26.1	29 5
	CS	34 4	32.5	32 1
	COM	22.2	30.9	32 6
1971	CC	63 5	65.7	65 7
	CS	64.6	66.1	66 8
	COM	54 2	66.7	64 4
1972	CC	61 0	63.3	63 2
	CS	61.9	63.4	62 3
	COM	64.0	63.7	64.9
1973	CC	53.2	51.2	55 6
	CS	54.5	53.3	55.9
	COM	36.4	52.8	55.1
1974	CC	-§	-	-
	CS	-	-	-
	COM	-	-	-
1975	CC	47.2	50.2	49.7
	CS	56.4	50.3	51.4
	COM	55.6	55.6	54.2
1976	CC	-	38.5	51.3
	CS	-	38.4	48.3
	COM	42.3	50.8	53.2
1977	CC	-	61.5	65.6
	CS	39.8	61.6	62.6
	COM	-	56.1	59.5
1978	CC	62.1	48.2	57.2
	CS	62.4	53.2	57.8
	COM	35.0	59.8	55.8
1979	CC	61.3	57.7	59.8
	CS	64.9	58.1	62.9
	COM	61.2	56.5	56.4
1980	CC	58.4	54.2	61.6
	CS	56.7	56.8	59.3
	COM	57.3	59.5	59.9
1981	CC	66.3	62.4	62.4
	CS	66.7	59.2	58.6
	COM	67.8	57.8	58.5
1982	CC	52.9	65.1	67.3
	CS	71.3	63.5	66.0
	COM	68.0	53.4	66.7
1983	CC	71.3	77.4	81.4
	CS	75.8	75.4	81.2
	COM	60.7	56.7	79.6
1984	CC	44.6	54.1	58.3
	CS	48.3	57.9	51.7
	COM	55.3	48.6	56.5

† CC, continuous corn; CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
§ No data recorded.

Table VII. Planting and Harvest Dates for Oats, Corn, and Soybeans.

Year	Planting Date			Harvest Date		
	Oats	Corn	Soybeans	Oats	Corn	Soybeans
1962	May 8	May 15	May 23	Jul 20	Oct 16	Sep 27
1963	-†	-	-	Jul 29	Oct 7	Oct 4
1964	-	May 21	May 21	Jul 17	Oct 16	Sep 23
1965	Apr 8	May 13	May 13	Jul 20	Oct 12	Oct 5
1966	Mar 18	May 20	May 20	Jul 18	Oct 18	Sep 27
1967	Apr 4	May 25	May 25	Jul 21	Oct 19	Oct 6
1968	Apr 2	May 7	May 17	Jul 26	Oct 18	Sep 27
1969	Apr 4	May 24	May 24	Jul 22	Oct 14	Oct 23
1970	Apr 1	May 22	May 22	Jul 14	Oct 12	Oct 5
1971	Mar 31	Apr 27	May 17	Jul 16	Oct 7	Sep 29
1972	Apr 3	May 12	-	Jul 25	Oct 24-25	Oct 13
1973	Apr 16	May 8	May 8	Jul 23	Oct 10	Sep 26
1974	Apr 12	Apr 29	May 15	Jul 22	Oct 21	Oct 8
1975	Apr 1	May 5	May 9	Jul 15	Oct 10	Oct 15
1976	Mar 25	Apr 22	May 6	Jul 26	Oct 21	Oct 12
1977	Apr 21	May 18	Jun 2	Jul 27	Nov 8-9	Oct 11, 17
1978	Apr 27	May 11	May 12	Jul 31	Oct 13	Oct 9
1979	Mar 31	May 14	May 17	Aug 8	Nov 14	Oct 18
1980	May 7	Jun 23	Jun 23	Aug 5	Oct 30	Oct 29
1981	Apr 1	May 14	May 19	Jul 23	Oct 27	Oct 5
1982	Apr 21	Apr 29	-	Jul 26	Nov 5	Oct 11
1983	May 18	May 18	May 18	Aug 8	Oct 25	Oct 3
1984	Apr 30	May 25	May 13	Aug 9	Nov 13-14	Nov 8

† Data not available.

Table VIII. Corn Grain Yields as Affected by Tillage and Rotation Combination Treatments.

Year	Rotation†	Plant Population at Harvest‡			Grain Yield		
		NT	MT	CT	NT	MT	CT
		thousands ha^{-1}			Mg ha^{-1}		
1962	CC	28.9	43.2	49.6	-††	5.92	5.83
	CS	33.3	43.5	51.4	-	6.00	5.83§
	COM	37.8	42.5	49.4	-	5.52	5.64#
1963	CC	35.6	35.8	45.7	6.98	7.06#	-
	CS	33.1	32.3	47.2	6.73	6.29	-
	COM	27.7	38.0	43.2	7.84§	7.18#	-
1964	CC	45.7	42.2	44.9	8.13	7.40	7.71
	CS	47.4	42.2	44.9	8 13	7.53	7.21
	COM	47.4	43.5	44.4	8.47	8.13	7.90
1965	CC	31.9	42.4	27.9	5.14	-	4.36#
	CS	27.7	43.5	29.9	4.52#	-	4.36#
	COM	32.8	44.2	29.9	5.25	-	4.80#
1966	CC	51.6	42.0	53.1	7.07	6.27§	5.50
	CS	52.8	44.7	50.9	6.98	5.06	5.02
	COM	51.4	40.7	47.7	7.28	-	6.27#
1967	CC	44.4	46.2	44.2	6.13	5.08#	5.92
	CS	37.5	41.5	41.0	4.89#	4.80#	5.11#
	COM	38.0	46.2	43.2	5.46§	6.75	6.31
1968	CC	64.4	43.2	65.4	10.3	8.99	8.91
	CS	63.2	67.2	66.9	10.0	8.99	9.05
	COM	65.7	64.0	62.0	11.0	10.1	10.0

(Continued)

† CC, continuous corn, CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage
†† Grain yields were not recorded due to excessive weed infestation, spraying error, or variable plant population.
# Two plots out of three were harvested.
§ One plot out of three was harvested.

Table VIII. Corn Grain Yields as Affected by Tillage and Rotation Combination Treatments. (Continued)

Year	Rotation†	Plant Population at Harvest‡			Grain Yield		
		NT	MT	CT	NT	MT	CT
		thousands ha^{-1}			Mg ha^{-1}		
1969	CC	45.2	59.0	52.6	7.00	7.38	7.81#
	CS	47.9	59.0	55.6	8.45	7.97	8.47
	COM	50.4	58.8	59.0	9.14	8.61	8.26
1970	CC	27.9	25.2	25.7	5.27	4.52§	4.16
	CS	31.9	29.1	29.9	6.86	5.56	5.33
	COM	20.5	28.6	27.7	-††	5.00	5.52
1971	CC	55.8	54.6	56.3	9.03	7.17	6.13
	CS	57.5	56.3	56.3	7.99	7.09	6.27
	COM	56.0	56.8	53.3	10.4	8.84	7.90
1972	CC	61.0	63.2	63.2	11.3	10.7	11.1
	CS	62.0	63.5	62.2	11.5	10.5	11.5
	COM	64.0	63.7	64.9	-	12.0	12.1
1973	CC	61.0	60.7	63.5	9.49	9.18	9.03
	CS	62.2	63.2	62.5	10.4	9.95	9.01
	COM	48.6	63.7	61.7	9.53§	10.30	9.76
1974	CC	60.5	60.2	57.5	9.60	7.51	6.44
	CS	57.5	61.2	57.3	9.70	7.88	7.15
	COM	59.0	59.0	58.5	9.66	7.51	7.44
1975	CC	47.2	45.2	46.4	8.13	5.98	5.87
	CS	47.9	47.2	47.4	8.05	6.10	4.77
	COM	48.6	46.9	48.6	8.36	6.44	6.44
1976	CC	44.0	42.7	37.5	7.69	6.21#	6.73
	CS	45.2	41.5	33.8	8.36	-	7.09#
	COM	43.7	43.2	44.0	8.74	7.17§	7.44
1977	CC	40.0	51.1	50.6	-	9.41	9.24
	CS	40.2	51.4	51.4	9.19#	8.86	8.97
	COM	39.5	53.3	52.6	-	9.22	9.99
1978	CC	53.3	51.4	52.3	10.2#	9.56#	8.78#
	CS	51.4	51.6	51.6	10.6	9.97	8.20
	COM	-	50.6	50.6	-	10.5	10.5
1979	CC	56.3	56.0	57.0	8.74	7.78	8.76
	CS	56.3	56.5	55.8	9.43	8.51	8.53
	COM	56.3	57.3	54.5	9.30	9.22	8.78
1980	CC	58.5	54.1	61.7	6.98	5.92	6.75
	CS	56.8	56.8	59.3	6.61	5.62	6.50
	COM	57.3	59.3	61.5	7.36	7.34	7.97
1981	CC	49.6	52.8	49.9	10.1	9.47	8.97
	CS	52.6	51.9	49.1	10.3	9.87	9.53
	COM	53.6	48.1	49.6	9.85	10.1	9.72
1982	CC	64.9	65.2	67.4	13.0#	10.3	9.39
	CS	66.9	65.4	66.2	12.9	9.74	8.26
	COM	66.2	62.0	66.7	12.7	11.8	10.7
1983	CC	71.4	76.0	75.3	7.28	5.90	5.30#
	CS	75.8	75.3	76.0	8.07	5.81	4.37
	COM	60.7	56.8	76.0	8.76	8.59	6.42
1984	CC	41.5	54.1	55.0	10.3§	9.70	8.57
	CS	48.3	55.2	52.6	9.09#	9.68	7.55
	COM	55.3	48.6	56.5	10.9	10.0	10.6

† CC, continuous corn, CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation.
‡ NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
†† Grain yields were not recorded due to excessive weed infestation, spraying error, or variable plant population
# Two plots out of three were harvested.
§ One plot out of three was harvested.

Table IX. Soybean, Oat, and Hay Yields as Affected by Tillage.

Year	Soybean†			Oats			Hay		
	NT	MT	CT	NT	MT	CT	NT	MT	CT
	Mg ha^{-1}								
1962	—‡	—	—	2.30	2.50	—	—	—	—
1963	1.95§	1.48	1.65	3.41	2.54	3.17	7.97	8.20	8.40
1964	2.08§	2.08§	2.22	3.36	3.56	3.69	8.60	8.58	9.41
1965	1.94	1.52	1.77	3.27	2.42	2.43	7.24	5.53	7.41
1966	1.46	0.86	1.38	2.09	2.42	2.08	5.64	7.15	8.47
1967	0.78	0.64	0.82	2.22	2.01	2.34	—	—	—
1968	2.07	1.59	1.46	4.09	3.66	3.16	7.75	8.69	8.74
1969	2.43	2.21	2.35	2.88	1.91	3.03	6.54	7.62	8.11
1970	1.63	1.16	1.20	3.87	3.55	1.89	7.03	7.59	7.77
1971	1.61	1.49	1.58	1.85	2.15	3.08	8.06	7.10	7.64
1972	—	2.46	2.16	3.24#	3.58	2.33#	9.21	7.93	7.71
1973	2.31	2.69	2.51	—	2.34	3.08	6.99	8.67	8.00
1974	2.48	1.83§	1.84#	4.26	3.73	3.94	7.37	9.36	10.30
1975	—	—	—	3.92#	4.09	3.46#	8.56	9.18	9.09
1976	2.31	2.33	2.42	—	1.65	1.50	7.19	9.12	8.65
1977	2.33	1.59	2.01	2.19	1.73	1.95	3.90	6.81	6.83
1978	2.48	1.62	1.83	—	1.74	1.54	—	6.36	7.12
1979	2.85	2.71	2.83	—	1.47	2.04	6.32	6.20	6.25
1980	—	—	—	1.55#	1.83	2.04	7.95	7.26	7.93
1981	2.59	2.63	2.11	4.37	3.80	4.12	5.15	8.58	9.03
1982	1.85	2.01	1.39	3.76#	3.33	3.33	4.32	5.67	4.55
1983	2.36	2.25#	1.33	2.29	2.20#	2.47	4.64	4.10	4.10
1984	—	—	—	2.29#	2.57	2.04#	5.08	4.86	4.93

† NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
‡ Poor weed control, herbicide damage, late planting date or weather stress resulted in erratic stands so that yield data were not recorded.
§ One plot of three was harvested.
# Two plots of three were harvested.

Table X. Nutrient Composition of Corn Ear Leaf Samples at 50% Silking.

Tillage†	Rotation‡	Year	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Sr	Mo
			Concentration of Element Specified											
			%					mg kg^{-1}						
NT	CC	1964	2.64	—§	—	—	—	—	—	—	—	—	—	—
		1965	—	0.29	1.37	0.88	0.55	103	144	11	20	36	23	2.1
		1967	3.20	0.27	2.17	0.63	0.31	70	115	7	8	17	23	1.0
		1970	3.07	0.27	2.30	0.47	0.21	97	167	8	11	31	24	1.0
		1971	2.65	0.28	2.35	0.44	0.32	67	121	12	11	33	28	0.7
		1972	3.09	0.45	2.56	0.50	0.32	59	149	19	12	29	30	1.4
		1973	2.72	0.44	2.19	0.68	0.45	60	149	9	12	40	36	1.1
		1978	2.69	0.34	1.99	0.72	0.55	51	111	17	7	20	17	1.4
	CS	1964	2.59	—	—	—	—	—	—	—	—	—	—	—
		1965	—	0.26	1.38	0.83	0.50	104	151	11	13	27	24	2.1
		1967	3.10	0.27	2.09	0.66	0.34	79	146	7	8	15	23	1.2
		1970	2.90	0.28	2.15	0.53	0.24	78	159	10	12	30	24	1.1
		1971	2.93	0.32	1.79	0.55	0.40	73	139	14	11	33	25	1.0
		1972	3.14	0.46	2.51	0.57	0.35	60	152	23	11	28	30	1.5
		1973	2.83	0.44	2.02	0.72	0.47	67	146	10	11	37	35	1.4
		1978	2.81	0.37	2.14	0.70	0.53	64	117	15	7	18	18	1.4
	COM	1964	2.55	—	—	—	—	—	—	—	—	—	—	—
		1965	—	0.27	0.91	1.03	0.78	89	118	10	14	30	32	3.1
		1967	3.38	0.33	2.25	0.61	0.38	72	150	6	9	16	24	1.5
		1970	2.90	0.37	2.15	0.53	0.28	69	167	10	13	23	25	1.2
		1971	3.20	0.34	2.25	0.55	0.41	62	137	14	13	37	29	1.2
		1972	3.24	0.52	2.35	0.63	0.47	60	167	22	13	27	31	1.7
		1973	2.86	0.49	1.89	0.71	0.51	44	136	10	12	36	36	1.4
		1978	—	—	—	—	—	—	—	—	—	—	—	—
MT	CC	1964	2.70	—	—	—	—	—	—	—	—	—	—	—
		1965	—	0.28	1.55	0.82	0.55	142	169	13	29	51	23	2.0
		1967	3.00	0.27	2.27	0.62	0.31	79	122	8	8	15	23	1.1
		1970	2.98	0.28	2.18	0.53	0.27	72	179	10	13	32	22	1.4
		1971	2.85	0.31	2.31	0.48	0.31	70	138	11	11	26	28	1.0
		1972	3.31	0.49	2.39	0.60	0.37	71	184	22	12	32	31	1.7
		1973	2.84	0.45	2.14	0.73	0.49	57	149	10	12	37	35	1.3
		1978	2.80	0.38	1.80	0.91	0.68	69	115	21	7	21	19	1.7
	CS	1964	2.50	—	—	—	—	—	—	—	—	—	—	—
		1965	—	0.25	1.50	0.78	0.47	153	183	13	15	36	16	1.2
		1967	2.88	0.25	2.38	0.60	0.28	85	151	9	7	14	20	1.2
		1970	3.15	0.30	2.00	0.60	0.29	95	206	11	12	31	23	2.1
		1971	3.03	0.34	2.10	0.53	0.34	88	154	14	12	35	27	0.9
		1972	3.32	0.47	2.38	0.61	0.32	76	154	26	9	40	23	1.7
		1973	2.88	0.45	2.12	0.72	0.47	58	143	10	12	33	35	1.4
		1978	2.70	0.38	1.83	0.92	0.62	71	120	20	6	19	18	1.6

(Continued)

† NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
‡ CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
§ Analysis not performed.

Table X. Nutrient Composition of Corn Ear Leaf Samples at 50% Silking.
(Continued)

Tillage†	Rotation‡	Year	Concentration of Element Specified											
			N	P	K	Ca	Mg	Mn	Fe	B	Cu	Zn	Sr	Mo
			%					mg kg^{-1}						
MT	COM	1964	2.59	—§	—	—	—	—	—	—	—	—	—	—
		1965	—	0.29	1.53	0.89	0.53	207	163	12	17	38	23	1.8
		1967	3.37	0.32	2.19	0.71	0.41	115	146	8	9	20	24	1.8
		1970	3.12	0.28	1.86	0.56	0.35	79	182	9	13	27	25	1.5
		1971	3.00	0.34	1.89	0.53	0.43	81	147	16	12	41	26	1.1
		1972	3.18	0.43	2.14	0.59	0.39	69	136	16	11	27	29	1.5
		1973	2.96	0.47	2.07	0.75	0.52	65	149	9	13	37	38	1.5
		1978	2.64	0.42	1.85	0.93	0.72	79	130	17	9	21	19	1.9
CT	CC	1964	2.59	—	—	—	—	—	—	—	—	—	—	—
		1965	—	0.28	1.38	0.85	0.55	109	179	14	20	33	20	2.2
		1967	3.05	0.30	2.35	0.67	0.34	87	136	9	8	17	22	1.5
		1970	2.65	0.27	2.00	0.52	0.31	75	189	10	12	28	22	1.8
		1971	2.83	0.35	2.12	0.58	0.37	99	166	14	13	37	26	1.5
		1972	3.12	0.42	2.76	0.51	0.32	58	119	15	12	27	28	1.4
		1973	2.87	0.45	2.08	0.82	0.51	58	153	10	13	37	37	1.7
		1978	2.64	0.35	1.81	0.75	0.58	56	110	16	7	18	16	1.4
	CS	1964	2.50	—	—	—	—	—	—	—	—	—	—	—
		1965	—	0.27	1.47	0.75	0.54	101	174	12	20	37	20	2.0
		1967	2.88	0.31	2.40	0.70	0.34	90	151	10	8	17	24	1.5
		1970	2.83	0.28	2.09	0.55	0.30	82	173	10	12	30	23	2.0
		1971	3.22	0.34	2.14	0.54	0.35	93	155	14	12	34	28	1.3
		1972	3.22	0.46	2.52	0.55	0.37	64	171	21	11	28	29	1.6
		1973	2.86	0.44	1.96	0.75	0.50	61	143	10	12	36	36	1.8
		1978	2.72	0.34	1.67	0.86	0.65	60	105	17	6	16	18	1.5
	COM	1964	2.50	—	—	—	—	—	—	—	—	—	—	—
		1965	—	0.27	1.38	0.87	0.56	183	181	14	28	48	35	2.3
		1967	3.02	0.30	2.18	0.67	0.35	103	124	7	9	17	26	1.4
		1970	2.77	0.27	1.92	0.58	0.34	88	168	11	13	127	24	1.7
		1971	2.55	0.35	1.87	0.61	0.45	70	161	13	13	36	30	1.7
		1972	3.13	0.48	2.51	0.69	0.44	80	117	18	13	30	32	1.7
		1973	2.98	0.44	2.03	0.72	0.50	64	146	9	11	37	37	1.3
		1978	3.00	0.40	1.74	0.87	0.73	79	135	19	8	20	21	1.7

† NT, no-tillage; MT, minimum tillage; and CT, conventional tillage.
‡ CC, continuous corn; CS, corn and soybeans in a two-year rotation; and COM, corn, oats, and meadow in a three-year rotation.
§ Analysis not performed.

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