RESEARCH BULLETIN 1180

DECEMBER 1986

Influence of Long-Term Tillage and Rotation Combinations on Crop Yields and Selected Soil Parameters

I. Results Obtained for a Mollic Ochraqualf Soil

W. A. Dick, D. M. Van Doren, Jr.,
G. B. Triplett, Jr., and J. E. Henry

The Ohio State University
Ohio Agricultural Research and Development Center

Wooster, Ohio

CONTENTS

**** ****

AGDEX 516, 531, 571

12-86-2.5M

Influence of Long-Term Tillage and Rotation Combinations on Crop Yields and Selected Soil Parameters
I. Results Obtained for a Mollic Ochraqualf Soil

W. A. DICK[1], D. M. VAN DOREN, JR.[1], G. B. TRIPLETT, JR.[2], and J. E. HENRY[1]

INTRODUCTION

No-tillage or zero-tillage, defined as a crop production system where weed control is accomplished entirely by herbicides and tillage is limited to the opening of a slot for seed and fertilizer placement, has experienced the greatest growth nationwide of any form of conservation tillage. In 1984, approximately 30 percent of the total cropland in the United States was in some sort of conservation tillage (3). No-tillage crop production rose from 3.6 percent of the total cropland in 1983 to 4.4 percent in 1984, approximately a 20 percent increase.

The increase in the use of conservation tillage may be attributed to several factors, the most important being the farmer's awareness that it is highly effective in controlling soil erosion (10). Other reasons for converting from a conventional, or plowed, system to a less intensive tillage system are fuel and labor cost reduction.

Conservation tillage experiments were begun in Ohio in 1962 and 1963 at different sites to investigate the effect of various tillage and rotation combinations on crop yield. With only slight modification, the same tillage and rotation variables have been continuously applied to the experimental sites resulting in a continuous record of more than 20 years.

Original questions to be answered by the experiment included: (1) how much tillage is required for satisfactory crop yield, (2) to what extent are crop rotations required for high corn (*Zea mays* L.) yields, and (3) how do tillage and rotation interact to influence corn yields? The first question was appropriate because the application of no-tillage for crop production was a rather new concept at the initiation of the experiment. The latter two questions involved the rotation variable because many farmers were moving towards monoculture of corn. This was due to cheaper nitrogen fertilizer which reduced the need for a legume in rotation and to the development of pesticides which could control disease and insects commonly associated with monoculture.

Results obtained for the effect of continuous application of various tillage and rotation combinations on crop yield have been published for three different sites in Ohio through the 1983 crop year (7). Corn yields were found to be positively influenced by no-tillage on the well-drained Wooster soil (Typic Fragiudalf), negatively influenced on the poorly drained Hoytville soil (Mollic Ochraqualf), and gave mixed results on the somewhat poorly drained Crosby soil (Aeric Ochraqualf). The negative response to no-tillage on the Hoytville soil was primarily due to the large decrease in yield obtained as a result of the continuous corn treatment. Yield responses of soybean (*Glycine max* L.) and oats (*Avena sativa* L.) to tillage at the Wooster and Hoytville soil sites were similar to those observed for corn.

The effect of continuous application (19 and 18 years) of tillage and rotation combinations on selected soil chemical and biological properties have also been published for the Wooster and Hoytville sites (5,6). No-tillage results in significantly higher organic C, organic N, and soil enzyme activities in the 0 - 7.5-cm layer of both the Wooster and Hoytville soils than observed for the same soil layer under conventional tillage. The increased concentrations of 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, concentrations of the various soil parameters were generally lower under no-tillage compared to conventional tillage. There was no effect of tillage below the 15-cm depth for the Wooster soil.

Besides crop yields and data for a single sampling of soil profiles, a large amount of other data have been collected during the course of the tillage and rotation experiments since they were begun in 1962

[1] Associate and Emeritus Professors of Agronomy and Assistant Professor of Agricultural Engineering, respectively, of The Ohio State University (OSU)/The Ohio Agricultural Research and Development Center (OARDC).

[2] Emeritus Professor of Agronomy, OSU/OARDC and Professor, Mississippi State University.

Table 1. Physical Characteristics of Hoytville Silty Loam at Northwest Branch, OARDC, in Wood 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 X cm^3 cm^{-3}				g cm^{-3}
A_p	0-23	8-23	5.7	21	42	37	47.6	40.6	37.6	22.2	1 30
B_{21g}	23-33	25-30	2.6	16	38	46	46.2	43.0	41 1	24.5	1.43
	33-46	36-43	1.5	16	36	48	44.7	42.2	40.5	25.4	1 47
B_{22g}	46-56	48-53	1.1	16	36	48	-	-	-	-	-
	56-69	58-66	0.8	16	36	48	42.0	40.2	39 0	25.2	1 54
B_{3g}	69-79	69-76	0.6	16	36	48	40.7	38.3	37.3	26.1	1 59
	79-91	81-89	0.7	17	38	45	39.7	37.7	35.3	27.5	1 62
	91-107	97-104	0.8	18	37	45	40.4	38.4	36.2	25.8	1 59
B_3-C_{1g}	107-132	117-124		20	37	43					1 61
C_1	132-152	140-147		23	39	37					
C_2	152-183	165-173		20	37	44					
	183-213	193-201		19	39	43					
	213-244	224-231		22	42	36					
C_3	244-274	254-262		24	40	36					

† Data obtained by the Ohio State University Soil Survey Laboratory from a site within 1 km of the long-term tillage and rotation plots
‡ Determined by the Walkley-Black method as reported by reference (1).
§ Determined as reported in reference (4) for pipette analysis.
# Determined during desorption of 7 5 cm long by 7 cm diameter "undisturbed" cylinders of soil as reported in reference (12) for 0 to 0 33 bar, and of disturbed samples as reported in reference (15) for 15 bar

and 1963. The purpose of this report is to collect, in one publication, the data on crop growth and yield and on soil physical, chemical, and biological properties that have been recorded at the Hoytville soil site since 1963. A similar report (8) describes the Wooster site. It is hoped that this comprehensive compilation of data will stimulate other researchers, with areas of expertise other than the authors, to recognize trends we might have overlooked in our data and to apply their knowledge to solving problems that are associated with reduced, and especially no-tillage, systems.

MATERIALS AND METHODS

SITE CHARACTERISTICS

Soil and Drainage: The Hoytville soil is a member of the fine, illitic, mesic family of Mollic Ochraqualfs. Hoytville soils consist of dark-colored, very poorly drained soils that developed in fine-textured, calcareous glacial till. They occur in level, broad areas on the lake plain in northwest Ohio. A typical profile in a cultivated field consists of 0 - 20 cm, very dark gray, firm clay; 20 - 60 cm, dark grayish-brown, very firm clay mottled with yellowish-brown and brownish-yellow; 60 - 100 cm, grayish-brown to dark grayish-brown very firm clay mottled with yellowish-brown; and 100 + cm, firm clay mottled with grayish-brown and yellowish-brown, glacial till, calcareous. When wet, the soil has poor surface and internal drainage but cracks substantially when dry.

Selected physical characteristics of the Hoytville soil, near the experimental site located at the OARDC Northwest Branch in Wood County, are listed in Table 1. Figure 1 shows the distribution of the Hoytville soil series in Ohio. Results obtained in this study are considered applicable to other Mollic Ochraqualfs having similar climatic conditions and supplemental drainage.

Subsurface tile drains of 10 cm inside diameter were installed in 1952 at 17 m lateral spacing and 1.2 - 1.4 m deep. Tile line direction is perpendicular to crop rows. Surface drainage is poor at this site because the slope of the land is less than one percent.

Crop and Tillage History: The experimental site had been cropped six years prior to the initiation of the experiment in 1963 to corn, oats, and meadow in a three-year rotation. Tillage consisted of fall plow (20 cm depth) plus follow-up passes with a disc (10 cm) for 4 out of the 6 years. Tillage was not applied to the meadow once seeding was completed.

Climate: Mean monthly climatic conditions for the years of the experiment (1963-1984) are listed in Appendix Tables I and II.

EXPERIMENTAL DESIGN

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

1. **Conventional Tillage (CT).** Plowed each fall with a moldboard plow to a depth of 20-25 cm. One or two additional 10-cm deep secondary tillage operations were applied in the spring prior to planting for seedbed preparation.

2. **Minimum Tillage (MT).** Plowing was accomplished each fall with a moldboard plow to a depth of 20-25 cm. No other tillage was applied prior to planting. In October 1982 the MT plots for corn, soybeans, and oats were tilled using a paraplow to 35 cm depth. The paraplow is a tillage implement designed to loosen the subsurface soil layers while leaving the surface residue relatively undisturbed. In 1983 this treatment was converted to a NT treatment so that at the time this report was completed a 2-year history of NT preceded by 1 year paraplow and 19 years of plow-plant had been applied to what is called the MT treatment.

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

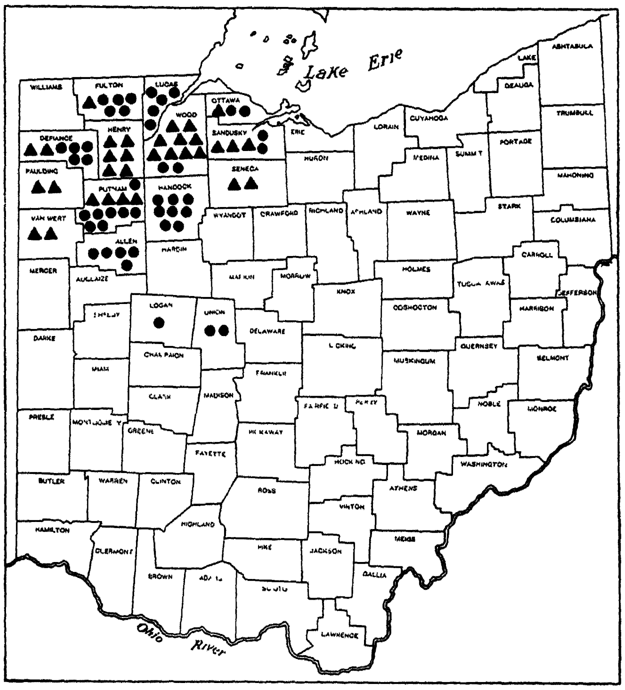

Figure 1. Distribution of the Hoytville soil series in Ohio. Each solid circle represents 1,000 hectares and each solid triangle represents 10,000 hectares. The experimental site for which data is reported is located in Wood County.

Rotation Variables:

1. **Continuous corn (CC).**

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

3. **Corn-oats-meadow in a 3-year rotation (COM).** Each crop appeared in the experiment each year. The meadow crop consisted of alfalfa (*Medicago sativa* L.) or an alfalfa-orchardgrass (*Dactylis glomerata* L.) mixture from 1963 to 1979, perennial ryegrass (*Lolium perenne* L.) from 1980 to 1983 and red clover (*Trifolium pratense* L.) in 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 plots of a complete randomized block design with three replications. The combinations of tillage and rotations were continued on the same plots, with the exception of the change in the MT treatment, from 1963 through 1984.

Management Practices:

1. **Plot size**. Plots were 30.5 m long and 6.4 m wide. Each plot of corn and soybeans had 6 planted rows until 1968 when 8-row plots were begun.

2. **Fertilizer and Lime.** Nitrogen was added to the plots primarily as ammonium nitrate which was broadcast in the spring prior to any tillage. From 1963 through 1966 the P and K was applied in a band by the planter 5 cm below and 5 cm to the side of the seed. Beginning in 1967 most of the P and K was broadcast applied, generally in the late fall. Manganese was foliar applied to soybeans in most years as $MnSO_4$. Lime was broadcast in the winter as required to maintain a pH in the Ap horizon of the continuous corn plots at 6.0 or higher, 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 measures were required. By far the greatest amounts of pesticides were applied to the corn and soybeans with the NT treatments receiving approximately 25 percent more herbicide material than the MT and CT treatments. Appendix Table IV provides a complete record of the pesticides applied and Appendix Table V lists the common names of the pesticides used along with their chemical names.

During several corn and soybean crop years the plots were split and various fungicides were applied. Information pertaining to these experiments are not included in the Appendix but will be discussed in more detail in the Results and Discussion section.

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. During the years of 1978 through 1984 the soybean plots were split and a Phytophthora resistant (tolerant) and a susceptible cultivar were grown in the same year. Row spacing for corn and soybeans was 102 cm until 1968 when the distance between rows was reduced to 76 cm. Oats were seeded to rows spaced 18 cm apart for all years.

When corn plants were 0.2 - 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.

Prior to harvest, plots were shortened to 29.5 m by trimming 0.5 m from each end. Harvest lengths were sometimes shorter in order to achieve equal stand or weed control among treatments. Grain was harvested after drying in the field to moisture contents safe for storage. Corn and soybean yields were obtained by harvesting the center four rows (1963-1967), the center six rows (1968-1969) and rows 2-3 separately from rows 6-7 (1970-1984). Oat and meadow yields were measured by cutting a swath of a known width from the center of the plot. Generally, all treatments of each crop each year were harvested on the same date. Planting and harvest dates for oats, corn, and soybeans are recorded in Appendix Table VII.

A moisture reading of the grain 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 sample was weighed wet in the field, brought to the laboratory and dried at 60^0C, and reweighed to determine moisture content. A summary of corn grain yields and of soybean, oat, and hay yields appears in Appendix Tables VIII and IX. Corn and soybean yield data for individual plots which had weed growth causing severe competition and which exhibited a plant density below the threshold level were not included in the Appendix tables. Oat and hay plots were occasionally 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 - 20 cm were obtained from all 54 plots in May of 1967 and were analyzed for available P, K, and pH by The Ohio State University soil and plant analysis laboratory. The plots were again sampled, according to the following procedure, in November of 1980 prior to tillage. Soil samples (1.9-cm soil cores) from 0 - 1.25 cm, 1.25 - 2.5 cm, 2.5 - 7.5 cm at 2.5-cm increments and from 7.5 - 30 cm at 7.5-cm increments from the NT plots and from 0 - 30 cm at 7.5-cm increments from the MT and CT plots were obtained after first removing easily identifiable surface plant materials, i.e., corn stalks and leaves. The soils were air-dried and ground to pass a 60-mesh sieve. Exchangeable bases using ammonium as the exchange cation (2), organic C, N, and P (5), pH (13), available P (14), total P (5), and soil enzyme activities (6) were measured in the 1980 soil profile samples. Available and Exchangeable K represent the same data although the units used are different when reporting available K versus exchangeable K.

The percentage of the soil surface covered by residues was determined for the no-tillage corn plots in 1964 through 1967 and in 1983. Residue cover values were determined by the point quadrat procedure (11).

NUTRIENT COMPOSITION OF CORN

Ear leaves were collected at silking during the years 1966 through 1970, 1972, and 1975. The leaves were dried, ground, and analyzed for N, P, K, Ca, Mg, Mn, Fe, Zn, B, Cu, Sr, and Mo by The Ohio State University soil and plant analysis laboratory. A summary of the data appears in Appendix Table X.

RESULTS AND DISCUSSION

Some of the data presented have been previously published, although without the great amount of supporting information given here. References to previously published data are 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 variables applied to the Hoytville silty clay loam soil are reported by Dick and Van Doren (7). Statistical analyses of yield data reported here were performed using the least squares method of Harvey (9) 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: Twenty-two years of corn emergence and grain yield observations as affected by tillage and rotation variables are summarized in Table 2. The

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}			
1963-1973	CC	6.40	7.28	7.28	Tillage = 0.16
	CS	7.34	7.60	7.41	Rotation = 0.16
	COM	7.34	7.53	7.60	Til x Rot = 0.29
1974-1984	CC	7.66	8.54	8.47	Tillage = 0.22
	CS	8.79	9.17	8.73	Rotation = 0.22
	COM	8.60	9.23	9.10	Til x Rot = 0.41
1963-1984	CC	7.03	7.91	7.85	Tillage = 0.14
	CS	8.10	8.35	8.10	Rotation = 0.14
	COM	7.97	8.35	8.35	Til x Rot = 0.25
		INITIAL POPULATION, Thousands ha^{-1}			
1963-1973	CC	49.4	50.3	54.2	Tillage = 1.3
	CS	49.6	54.5	53.1	Rotation = 1.3
	COM	49.3	51.7	53.7	Til x Rot = 2.3
1974-1984	CC	56.6	59.4	61.9	Tillage = 1.3
	CS	60.3	60.4	61.0	Rotation = 1.3
	COM	54.8	59.8	62.5	Til x Rot = 2.3
1963-1984	CC	53.0	54.9	58.1	Tillage = 0.9
	CS	55.0	57.5	57.0	Rotation = 0.9
	COM	52.1	55.8	58.1	Til x Rot = 1.6

† 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 (LSD) values were calculated by dividing the error mean square by the replicate number for the mean with the fewest observations

data are divided into 11-year periods, primarily to separate results obtained during the earlier years of the experiment when NT practices were not as well established from results obtained during the past 11 years. Comparison of the 1963-1973 and 1974-1984 corn yields show that equal yield increases were realized for both NT and plowed treatments. The increases in yield are a result of improved management practices such as increased addition of N fertilizer and increased plant populations. Similar yield increases for all the tillage treatments reflects the emphasis placed on maintaining equal stands across tillage and rotation treatments.

With equal stands and uniform weed control, however, NT practices were observed to produce significantly less yield. A significant interaction effect also is evident with the CC rotation being much more sensitive to NT than the CS or COM rotations. Over the 22-year period, corn grown continuously by NT yielded 0.85 Mg ha^{-1} less than that produced when CC was grown where a plowed treatment was applied. However, when corn was grown in rotation with another crop (e.g., the CS or COM rotations), the yield reduction associated with NT was much less ranging from 0 - 0.25 Mg ha^{-1} for the CS rotation and 0.38 Mg ha^{-1} for the COM rotation. There was essentially no difference in yield between the MT and CT treatments except for an average 0.25 Mg ha^{-1} higher yield for the MT treatment in the CS rotation.

The reasons for the reduced yields associated with NT, especially when continuous corn was grown, have not been clearly identified. However, root densities have been shown to be decreased under NT and the fungus *Pythium graminicola* Subr. has been implicated (16). Alleopathic mechanisms brought about by the decay of litter under moist and cool conditions, which can occur at a poorly drained site, may also be important.

From 1976 through 1979 the corn plots were split and one-half treated with a fungicide while the other half remained untreated. The results obtained from this experiment were mixed (Table 3). In 1977 and 1978 the fungicide increased yields in the NT plots to a larger extent than in the CT plots. Yield differences associated with tillage were eliminated in 1977 as a result of the fungicide treatment. However, in 1976 the fungicide-treated plots yielded less than the untreated plots where NT was applied but greater where CT was applied. The fungicide significantly decreased plant populations for both tillage treatments in 1979 so that meaningful comparisons could not be made. Further work will be required to adequately assess whether application of fungicides to soil where CC is grown using NT practices will help eliminate the yield decreases associated with NT.

Corn grain yields reported in Table 2 were obtained with plant populations adjusted to provide equal numbers across treatments. However, data of emerging populations (Table 2) indicate that when equal seed drop occurs, fewer plants emerge where NT is maintained than for the plowed treatments. An exception was the emergence of corn planted into soybean residues during the 1974-1984 period To ensure sufficient plant population for optimum corn yield, a 5 - 10 percent greater seed drop may be required for NT compared to where a plowing operation is applied.

Soybeans: Comparative yields for soybeans as affected by tillage under conditions of equal stand and weed control are summarized in Table 4. Greater yields were observed during the second half of the 22-year observation than during the first 11 years. The yield increase was much greater, however, for the MT and CT treatments than for NT. Between 1974-1984 the NT treatment exhibited only a 0.09 Mg ha^{-1} yield increase over the 1963-1973 period while the MT and CT treatments had yield increases of 0.40 and 0.30 Mg ha^{-1}, respectively.

Table 3. Interaction Effect of Tillage and Fungicide on Population and Yield of Corn for the Continuous Corn Rotation.

Year	Fungicide Treatment†	No-tillage Population	No-tillage Yield	Conventional tillage Population	Conventional tillage Yield	Yield $LSD_{0.05}$‡
		thousands ha^{-1}	Mg ha^{-1}	thousands ha^{-1}	Mg ha^{-1}	Mg ha^{-1}
1976	+	49.1	8.66	49.1	8.91	2.00
	−	49.1	9.66	49.1	8.09	
1977	+	48.4	9.35	48.4	9.16	1.22
	−	48.4	8.66	48.4	9.22	
1978	+	56.8	6.18	58.8	7.68	0.76
	−	57.0	5.56	56.8	7.42	

† In 1976, furalaxyl (methyl N-2,6-dimethyl-N-furoyl-(2)-alaninate) was applied as a spray on July 19 and August 25 Granular pyroxychlor was applied at time of planting of corn in 1977 In 1978, Dow 444 was applied at planting.

‡ The least significant difference (LSD) value is given for the tillage by cultivar interaction effect

During the 1963-1973 period, soybean yields were significantly (P = 0.05) lower where NT was continually applied. Inspection of the yearly yield data (Appendix Table IX) shows, however that there was little difference in yields between the various tillage treatments until 1971 or the ninth year after NT had been applied to the soil. During the 1974-1984 period yields averaged 0.45 Mg ha^{-1} lower for the NT than for the average of the plowed treatment.

Since 1978, soybean cultivars have been chosen on the basis of exhibiting resistance (tolerance) to *Phytophthora* root rot diseases. Inspection of yield results for these years (Appendix Table IX) indicates soybean yields, using NT practices and a *Phytophthora* resistant cultivar can be maintained at a level equal to or greater than where MT or CT practices have been maintained.

A specific test to determine whether *Phytophthora* root rot diseases may be decreasing yields under NT was conducted by splitting the soybean plots and growing both a susceptable and a resistant (tolerant) cultivar. The results (Table 5) indicate a significant interaction effect occurred in three of the four years in which valid data were obtained. For the 1978 and 1983 crop years equal yields were obtained for all the tillage treatments for the *Phytophthora* resistant cultivar and greater yields were obtained for the MT and CT (plowed) treatments for the susceptible variety. In 1982, the inverse was observed and the susceptible cultivar yielded higher under NT but lower for the plowed treatments. No significant interaction was observed in 1980 as both cultivars yielded significantly less under NT. During the 1984 crop year the susceptible cultivar had extremely poor stands for all tillage treatments while equal yields were observed across tillage treatments for the resistant (tolerant) cultivar.

The results to date suggest that a major reason for decreased soybean yields associated with NT is that the continued application of NT produces increased disease (*Phytophthora*) pressures. When a *Phytophthora*-susceptible cultivar is grown, the disease will be expressed to a greater extent where NT compared to the plowed treatments have been maintained. Selecting soybean cultivars which are resistant (tolerant) to *Phytophthora* eliminates the yield reduction associated with NT soybean production on this soil.

Oats and Hay: Less emphasis was placed on maintaining high oat yields compared to corn and soybean yields. Yield levels were low during the 1963-1973 period and did not improve during the 1974-1984 period (Table 6). Weed control and stand establishment were more often a problem for oats

Table 4. Soybean Grain Yields as Affected by Tillage.

Years	Tillage† NT	Tillage† MT	Tillage† CT	$LSD_{0.05}$‡
	Mg ha^{-1}			
1963-1973	2.34	2.54	2.52	0.15
1974-1984	2.43	2.94	2.82	0.25
1963-1984	2.39	2.73	2.67	0.14

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

Table 5. Interaction Effect of Tillage and Cultivars on Soybean Yields.

Year†	No-tillage‡		Minimum Tillage		Conventional Tillage		
	S	R	S	R	S	R	$LSD_{0.05}$
	Mg ha^{-1}						
1978	2.10	2.35	2.47	2.39	2.56	2.59	0.38
1980	1.73	2.07	3.47	2.87	2.61	3.32	0.47
1982	2.92	2.65	2.59	2.62	2.49	2.81	0.21
1983	2.02	3.25	2.67	3.09	2.71	3.23	0.20
1984	-§	3.21	-§	2.96	-§	2.78	

† Soybean yields for the 1979 and 1981 crop years were not recorded due to excessive hail and flood damage, respectively.
‡ S = susceptible cultivar 'Beeson' was grown in 1978 and 1980, 'Amsoy 71' in 1982, and 'Sloan' in 1983 and 1984. R = resistant (tolerant) cultivar. 'VS 295' was grown in 1978 and 1980, 'Gold Tag 1250' in 1982, and 'Asgrow 3127' in 1983 and 1984.
§ 'Sloan' beans had very poor stands and were killed and replanted to "Asgrow 3127". No yields were recorded.

than for the other crops. To compare oat yields as affected by tillage, data were included in the analysis only when it was felt that similar stand and weed control occurred for all treatments. The yield results (Table 6) indicate that a significant (P =0.05) yield reduction was associated with NT. The reasons for the yield response of oats as affected by tillage has not been investigated.

Hay yields were only rarely recorded due primarily to poor stand establishment. No statistical analyses were performed on the data.

Comments: The yield decreases associated with NT on a poorly drained soil may very well be the result of a combination of several chemical, biological, and physical factors. To date, the interaction of tillage and disease has received the most study and seems to explain some of the negative effects of NT on crop yields. However, further studies need to be conducted to determine interactive effects of tillage and other variables beside disease such as soil fertilizer and nutrient chemistry, and physical parameters.

SOIL MEASUREMENTS

Residue Cover: No-tillage plots maintained variable amounts of residue on the soil surface relating to the crop rotation (Table 7). Neither the CC nor the COM rotation consistently provided the highest percentage of residue cover. The average residue cover values for the CC and COM rotation for the five years of observation were very similar. The lowest amount of residue cover for the corn year occurred for the CS rotation which also produces the lowest amount of residues. The percentage of ground covered by residues after the first year of applying this rotation will reduce soil erosion about 50 percent compared with CT practices.

Soil Fertility: After four complete growing seasons, 0-20 cm soil samples were collected and analyzed for pH, available P, and available K. Soil pH was not significantly altered by the application of the various tillage and rotation treatments (Table 8). Available P and K were higher in the NT plots but the differences were not statistically significant and would not be expected to cause crop yield differences.

Table 6. Oat Grain Yields as Affected by Tillage.

Years	Tillage† NT	Tillage† MT	Tillage† CT	$LSD_{0.05}$‡
	Mg ha^{-1}			
1963-1973	2.59	2.92	2.94	0.19
1974-1984	2.54	2.89	2.87	0.20
1963-1984	2.57	2.90	2.91	0.14

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

Table 7. Percentage of Soil Surface Covered by Residues in the No-tillage Corn Plots.

Year	Sampling Date	Rotation† CC	Rotation† CS	Rotation† COM
		%		
1964	7/29	36	12	28
1965	8/19	66	40	50
1966	9/23	62	46	90
1967	8/29	92	81	94
1968	6/21	77	47	87
Average ($LSD_{0.05}$ = 15)‡		67	45	70

† 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 (LSD) value was calculated by making each year equal to one replication and each tillage mean equal to one observation.

Results obtained after 19 growing seasons (Table 9), however, showed a significant effect of both tillage and rotation on soil fertility parameters. The surface of the NT and CC treated plots were almost a full pH unit lower than for the other treatments. The effect of this treatment continued to be evident to a depth of 22.5 cm. The response of pH to tillage and rotation occurred as a result of surface application of ammonium nitrate fertilizer (see Appendix Table III). The largest amount of fertilizer N is added to the corn crop which occurs every year for the CC rotation but only every second and third year for the CS and COM rotation, respectively. Surface application of the fertilizer N would, therefore, be expected to have the greatest effect in those plots where the NT and CC treatment combination was applied.

Tillage caused a significant change in available P concentrations in the soil profile. Concentration of available P in the 0 - 7.5 cm soil layer were approximately 4 to 5 times greater in the NT plots than in the plowed plots. In the lower soil layers, however, the inverse was true. Below 15 cm, available P levels were below 8 mg kg^{-1} for all the NT treatments. The crop must, therefore, be able to obtain sufficient P from the surface layers and inspection of corn leaf compositions (Appendix Table X) indicate that at least through the 1975 season, similar amounts of P were taken up from the different tillage treatments despite the stratification of P within the NT soil profile. Although the available P is found primarily within the 0 - 7.5 cm soil layer, because of its high concentration, it may be very efficiently removed from the soil solution. There was little effect of crop rotation on available P concentrations.

Available K demonstrated similar trends to tillage and rotation as noted for available P. The magnitude of response, however, was not as great. Concentrations were approximately 1.7 times greater in the 0 - 7.5 cm soil layer of the NT plots compared to the plowed plots and 1.2 times less in the 22.5 - 30.0 cm soil layer. The CC rotation plots exhibited lower available K concentrations than the other rotations due to the greater demand for K by the corn crop and its subsequent removal in the corn grain.

Concentration of the exchangeable bases (summation of Ca, Mg, K, and Mn) was not significantly affected by tillage and rotation (Table 9) except in the 0 - 7.5 cm soil layer where the NT treatment had a lower concentration of exchangeable bases. Inspection of exchangeable Ca data in Table 10 indicates that lower concentrations of Ca were responsible.

Organic C, N, and P: The distribution of organic C, N, and P and pH in soil profiles as affected by the long-term application of NT has been reported previously (5). A complete summary of this organic C, N, and P profile data is provided in Table 11. Organic C concentrations were found to be significantly affected by tillage and rotation. The NT treatment resulted in concentrations of organic C in the 0-7.5 cm soil layer that were approximately 1.5 times greater than the plowed treatments. Visual inspection of the surface soil layers clearly indicates a more aggregated and darker colored soil in the NT plots. The 7.5-15.0 cm soil layer also had organic C concentrations which were significantly higher in the NT plots. However, the inverse was observed in the two lowest soil layers where the plowed treatments had significantly higher organic C concentrations. Organic C that is mineralized in the lower soil layers of the NT treated plots is not replaced by mixing of surface deposited residues. The addition of plant roots to the lower portion of the soil profile also seems to be insufficient to sustain the organic C concentrations under NT that are comparible to those under the plowed treatments.

Organic C concentrations were significantly affected by crop rotation (Table 11), with the COM

Table 8. pH, Available P, and Available K in 0-20 cm Soil Samples (May, 1967).

Rotation†	pH‡			Available P			Available K		
	NT	MT	CT	NT	MT	CT	NT	MT	CT
				mg kg^{-1}					
CC	7.0	7.2	6.8	9	11	14	144	141	144
CS	6.9	7.0	7.0	11	12	10	156	145	138
COM	7.0	6.8	7.1	17	11	9	152	145	135
	STATISTICS ($LSD_{0.05}$)§								
	T	R	T by R	T	R	T by R	T	R	T by R
	0.19	0.19	0.33	5	5	8	12	12	21

† 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 (LSD) values are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R)

Table 9. Concentrations of Soil Fertility Parameters in Profile Samples (November, 1980).

Rotation†	Soil Layer	pH‡			Available P			Available K			Exchangeable Bases††		
		NT	MT	CT	NT	MT	CT	NT	MT	CT	NT	MT	CT
	cm				mg kg^{-1}						cmol(+) kg^{-1}		
CC	0- 1.25	5.9			286			426			19.8		
	1.25- 2.5	5.5			242			319			18.6		
	2.5 - 5.0	5.7			145			263			20.4		
	5.0 - 7.5	6.0			66			224			21.9		
	0- 7.5	(5.8)#	7.0	6.7	(158)	33	35	(287)	182	174	(20.5)	23.5	22.7
	7.5 -15.0	6.4	7.2	7.0	21	35	30	176	174	163	23.8	24.1	23.1
	15.0 -22.5	6.6	7.2	7.0	5	37	35	146	180	173	21.5	24.0	23.5
	22.5 -30.0	7.0	7.2	7.2	3	21	24	145	170	174	21.3	23.1	24.2
CS	0- 1.25	6.8			287			480			23.9		
	1.25- 2.5	6.7			236			373			22.5		
	2.5 - 5.0	6.8			164			291			23.1		
	5.0 - 7.5	6.8			77			223			23.4		
	0- 7.5	(6.8)	7.0	7.1	(168)	38	35	(314)	200	181	(23.2)	23.9	23.4
	7.5 -15.0	6.9	7.1	7.2	21	38	36	171	178	179	23.0	23.2	23.9
	15.0 -22.5	6.9	7.1	7.2	7	41	35	144	199	182	22.2	23.4	24.0
	22.5 -30.0	7.0	7.2	7.3	3	30	22	137	189	166	20.3	23.4	22.7
COM	0- 1.25	6.7			272			592			26.4		
	1.25- 2.5	6.8			229			483			24.8		
	2.5 - 5.0	6.9			157			366			24.9		
	5.0 - 7.5	7.0			78			284			24.9		
	0- 7.5	(6.9)	6.8	6.9	(162)	46	44	(396)	213	212	(25.1)	22.7	22.9
	7.5 -15.0	7.0	7.0	7.2	28	43	35	202	195	176	24.9	23.7	23.8
	15.0 -22.5	6.7	7.1	7.2	8	38	39	147	194	180	25.6	24.0	24.1
	22.5 -30.0	7.2	7.1	7.3	5	21	21	142	168	161	22.6	22.5	23.1
		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	0.23			68			159			0.8		
	1.25- 2.5	0.34			100			63			3.6		
	2.5 - 5.0	0.37			75			44			7.5		
	5.0 - 7.5	0.33			40			24			5.7		
	0- 7.5	0.11	0.11	0.20	17	17	30	16	16	27	1.4	1.4	2.5
	7.5 -15.0	0.12	0.12	0.21	7	7	16	14	14	25	2.2	2.2	3.7
	15.0 -22.5	0.23	0.23	0.40	5	5	9	13	13	22	1.7	1.7	2.9
	22.5 -30.0	0.08	0.08	0.14	4	4	8	12	12	20	1.0	1.0	1.8

† 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, Mn, and K.

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

§ Least significant difference (LSD) values are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R)

Table 10. Concentrations of Total P and Exchangeable Ca, Mg, Mn, and K in Soil Profiles (November, 1980).

Rotation†	Soil Layer	Total P‡			Exchangeable Ca			Exchangeable Mg			Exchangeable Mn			Exchangeable K		
		NT	MT	CT	NT	MT	CT	NT	MT	CT	NT	MT	CT	NT	MT	CT
	cm	mg kg^{-1}			cmol(+) kg^{-1}											
CC	0- 1.25	1460			13.7			5.0			0.058			1.09		
	1.25- 2.5	1350			12.8			4.9			0.047			0.82		
	2.5 - 5.0	1160			14.6			5.1			0.044			0.67		
	5.0 - 7.5	946			16.3			5.0			0.040			0.57		
	0- 7.5	(1170)§	889	887	(14.7)	18.3	17.7	(5.0)	4.7	4.6	(0.046)	0.036	0.034	(0.73)	0.47	0.44
	7.5 -15.0	857	905	898	18.6	19.0	18.0	4.7	4.6	4.7	0.028	0.035	0.033	0.45	0.44	0.42
	15.0 -22.5	780	903	902	17.2	18.9	18.4	3.9	4.7	4.7	0.029	0.035	0.036	0.37	0.46	0.44
	22.5 -30.0	642	785	800	17.4	18.4	19.2	3.5	4.2	4.5	0.031	0.035	0.039	0.37	0.43	0.45
CS	0- 1.25	1530			16.7			5.9			0.062			1.23		
	1.25- 2.5	1370			15.6			5.9			0.047			0.95		
	2.5 - 5.0	1190			16.3			6.0			0.036			0.74		
	5.0 - 7.5	993			17.2			5.6			0.032			0.57		
	0- 7.5	(1210)	898	898	(16.6)	18.8	18.5	(5.8)	4.5	4.4	(0.041)	0.032	0.039	(0.80)	0.51	0.46
	7.5 -15.0	819	872	895	17.7	18.3	18.9	4.9	4.4	4.5	0.026	0.032	0.039	0.44	0.46	0.46
	15.0 -22.5	712	888	889	17.8	18.5	19.0	3.9	4.4	4.5	0.020	0.031	0.040	0.37	0.51	0.46
	22.5 -30.0	639	811	792	16.4	18.5	17.9	3.5	4.3	4.3	0.028	0.033	0.034	0.35	0.48	0.42
COM	0- 1.25	1540			18.6			6.2			0.044			1.43		
	1.25- 2.5	1410			17.4			6.1			0.036			1.24		
	2.5 - 5.0	1200			17.9			6.0			0.029			0.94		
	5.0 - 7.5	1030			18.6			5.5			0.029			0.73		
	0- 7.5	(1240)	910	892	(18.2)	17.7	17.8	(5.9)	4.4	4.5	(0.033)	0.030	0.033	(1.02)	0.55	0.54
	7.5 -15.0	893	894	881	19.6	18.5	18.7	4.8	4.7	4.6	0.025	0.025	0.029	0.52	0.50	0.45
	15.0 -22.5	786	893	883	21.2	18.8	19.0	3.9	4.6	4.7	0.024	0.027	0.029	0.38	0.50	0.46
	22.5 -30.0	666	784	780	18.8	17.7	18.3	3.4	4.3	4.4	0.026	0.029	0.029	0.36	0.43	0.41
		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	56			0.2			0.71			0.013			0.41		
	1.25- 2.5	166			3.0			0.79			0.011			0.16		
	2.5 - 5.0	109			6.7			1.21			0.010			0.11		
	5.0 - 7.5	84			5.0			0.78			0.009			0.06		
	0- 7.5	29	29	51	1.3	1.3	2.2	0.27	0.29	0.47	0.004	0.004	0.007	0.04	0.04	0.07
	7.5 -15.0	30	30	52	2.0	2.0	3.4	0.31	0.31	0.54	0.004	0.004	0.007	0.04	0.04	0.06
	15.0 -22.5	56	56	97	1.7	1.7	1.9	0.20	0.20	0.35	0.008	0.008	0.014	0.03	0.03	0.06
	22.5 -30.0	37	37	64	1.1	1.1	1.9	0.19	0.19	0.32	0.007	0.007	0.013	0.03	0.03	0.05

† 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, 1.25-2.5, 2.5-5.0, and 5.0-7.5 cm soil increments.
# Least significant difference (LSD) values are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R).

Table 11. Concentrations of Organic C, N, and P in Soil Profile Samples (November, 1980).

Rotation†	Soil Layer	Organic C‡			Organic N			Organic P		
		NT	MT	CT	NT	MT	CT	NT	MT	CT
	cm	%						mg kg^{-1}		
CC	0- 1.25	4.54			0.381			240		
	1.25- 2.5	3.41			0.341			268		
	2.5 - 5.0	2.62			0.286			336		
	5.0 - 7.5	2.27			0.251			354		
	0- 7.5	(2.96)§	1.95	2.10	(0.299)	0.216	0.224	(315)	394	371
	7.5 -15.0	2.17	1.87	2.09	0.235	0.216	0.227	441	393	394
	15.0 -22.5	1.63	1.86	2.05	0.192	0.213	0.229	381	372	388
	22.5 -30.0	0.95	1.64	1.81	0.129	0.189	0.200	234	339	310
CS	0- 1.25	3.86			0.361			353		
	1.25- 2.5	2.95			0.297			319		
	2.5 - 5.0	2.39			0.258			341		
	5.0 - 7.5	2.11			0.234			368		
	0- 7.5	(2.64)	1.90	1.83	(0.274)	0.207	0.202	(348)	374	372
	7.5 -15.0	2.06	1.85	1.87	0.218	0.209	0.206	354	351	369
	15.0 -22.5	1.73	1.88	1.81	0.194	0.212	0.205	317	352	362
	22.5 -30.0	0.95	1.58	1.37	0.130	0.189	0 166	260	310	315
COM	0- 1.25	5.16			0.474			450		
	1.25- 2.5	3.70			0.365			401		
	2.5 - 5.0	2.91			0.315			417		
	5.0 - 7.5	2.48			0.271			419		
	0- 7.5	(3.27)	2.13	2.13	(0.335)	0.232	0.232	(421)	401	363
	7.5 -15.0	2.27	2.06	2.06	0.243	0.227	0.227	421	381	378
	15.0 -22.5	1.73	2.00	2.04	0.204	0.221	0.219	366	364	367
	22.5 -30.0	1.01	1.43	1.60	0.140	0.175	0.183	276	323	330
		STATISTICS ($LSD_{0.05}$)#								
		T	R	T by R	T	R	T by R	T	R	T by R
	0- 1.25		0.65			0.037			156	
	1.25- 2.5		0.75			0.073			194	
	2.5 - 5.0		0.42			0.032			147	
	5.0 - 7.5		0.09			0.028			96	
	0- 7.5	0.12	0.12	0.20	0.012	0.012	0.020	46	46	79
	7.5 -15.0	0.09	0.09	0.16	0.007	0.007	0.013	28	28	49
	15.0 -22.5	0.11	0.11	0.20	0.009	0.009	0.016	51	51	88
	22.5 -30 0	0.16	0.16	0.28	0.011	0.011	0.019	28	28	49

† 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 layers
# Least significant difference (LSD) values are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R)

rotation having the highest concentrations and the CS rotation the lowest. The difference in the build-up of organic C at the soil surface associated with the various rotations on the NT plots corresponds to the amount of total residue produced by the rotation.

Organic N concentrations closely followed the pattern observed for organic C. Concentration at the soil surface in the NT plots was approximately twice as great as in the plowed plots. In the lower soil layers (15.0-22.5 cm and 22.5-30 cm) the organic N concentrations were significantly lower in the NT compared to the plowed plots.

Tillage did not affect organic P concentration except in the 22.5 - 30 cm soil layer where the NT treatment resulted in a significant decrease. However, rotation was a significant factor in influencing organic P concentrations in the surface soil layers of the NT plots. The CC rotation yielded a significantly lower concentration than did the CS and COM rotations, which is unlike the organic C and N data where the lowest concentrations were associated with the CS rotation.

The organic fraction of the soil is often considered beneficial as it provides a storehouse of plant nutrients and serves as the aggregating material for soil particles. The long-term application of NT practices on the Hoytville silty clay loam soil provides both adequate residue cover to prevent soil erosion and is increasing organic matter content in the surface soil layers. The result is a more beneficial physical and chemical environment for plant growth. On the negative side, however, fertilizer nutrients that are applied may be immobilized in this carbon rich zone of soil and/or the microenvironment of the residue-soil interface may provide an ideal habitat for disease and insect pests.

Enzyme Activities: Soil enzyme activities are often used as indices of microbial activity and play an important role in the cycling of C, N, P, and S in soil. Six soil enzymes were assayed in air-dried soil profile samples collected from the NT and CT corn plots. The results were summarized in a previous publication (6). A more complete summary of the enzyme activity data is provided in Table 12 and shows NT significantly increased activity in the surface soil layers but decreased activity in the lower profile layers when compared to the CT. Rotations also influenced activity with the COM rotation stimulating the greatest activity and the CS rotation the least. Enzymes which are particularly sensitive to soil pH exhibited a significant interaction effect in the 0 - 7.5 cm soil profile layer. The low pH in the CC rotation, for example, significantly inhibited activity of alkaline phosphatase but stimulated activity of acid phosphatase.

With the exception of amidase, the activity of soil enzymes were found to be significantly correlated with organic C concentrations. Soil pH did not affect activity except where it was 6.0 or lower as was the case for continuous corn grown by NT practices. The effect of increased enzyme activity in the upper portion of the soil profile where NT has been practiced on a long-term basis 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 22 years, with all crops appearing each year. The soil was a poorly drained Hoytville silty clay loam, a nearly level Mollic Ochraqualf soil having tile at 1.2-1.4 m depth and at 17 m lateral spacing. The original objective of the experiment was to create equal stands of each crop within a year and equally effective weed control. 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 18th year of the experiment.

Corn yields were consistently lower where NT practices were maintained, especially where the CC rotation was applied. Over the 22-year period, corn grown by NT practices averaged 0.45 Mg ha^{-1} less than where the plowed treatments were applied. The CC and NT treatment combination averaged 0.88 Mg ha^{-1} less than the next lowest treatment combination (MT, CC). Similar results were obtained for yields of soybean and oats where NT yields, averaged over the 22 years, were 0.31 and 0.33 Mg ha^{-1} lower, respectively, than were the yields associated with the plowed treatments. However, four years of data in which *Phytophthora* root rot resistant (tolerant) soybean cultivars were compared to susceptible cultivars suggest that the yield losses associated with the NT treatment can be greatly reduced by using resistant cultivars. To provide corn yields using NT practices that were equal or better than yields obtained using CT practices on the poorly drained soil, it was necessary to practice crop rotation or to apply tillage to the soil.

Soil measurements made after 18 years indicated a significant effect of tillage on pH and n the distribution of organic matter, plant nutrients, and enzyme activities in soil profiles. The 0 - 7.5 cm soil layer of the NT plots was found enriched in concentration of the above mentioned parameters when compared to the MT and CT plots. However, in the lower profile samples, such as the 22.5 - 30 cm samples, concentrations of parameters were often sig-

Table 12. Activity of Enzymes in Soil Profile Samples Collected from Plots Planted to Corn (November, 1980).

		Activity of Enzyme Specified‡											
	Soil	Alkaline Phosphatase§		Acid Phosphatase		Aryl-Sulfatase		Invertase		Amidase		Urease	
Rotation†	Layer	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT	NT	CT
	cm												
CC	0- 1.25	174		820		106		265		17.5		236	
	1.25- 2.5	95		578		103		96		29.0		145	
	2.5 - 5.0	93		338		126		46		30.9		143	
	5.0 - 7.5	110		304		160		58		26.2		185	
	0- 7.5	(113)††	149	(447)	318	(130)	127	(95)	79	(26.8)	19.5	(173)	147
	7.5 -15.0	145	168	291	281	184	151	18	57	27.6	17.8	179	169
	15.0 -22.5	166	189	216	296	143	138	22	60	26.7	17.1	119	163
	22.5 -30.0	191	138	109	231	109	124	16	30	22.9	11.1	57	130
CS	0- 1.25	342		597		217		357		26.4		432	
	1.25- 2.5	213		468		228		177		23.5		315	
	2.5 - 5.0	233		329		242		90		24.0		313	
	5.0 - 7.5	189		278		214		48		23.0		267	
	0- 7.5	(233)	212	(380)	220	(226)	116	(135)	43	(24.0)	9.0	(318)	133
	7.5 -15.0	187	184	282	194	208	129	35	37	22.9	12.1	191	133
	15.0 -22.5	199	141	201	157	146	128	15	41	22.8	10.4	155	142
	22.5 -30.0	163	118	129	146	83	103	19	42	16.5	14.3	52	86
COM	0- 1.25	589		569		399		382		43.1		927	
	1.25- 2.5	453		511		399		195		47.3		811	
	2.5 - 5.0	351		389		362		114		37.9		550	
	5.0 - 7.5	271		362		321		114		33.4		413	
	0- 7.5	(381)	227	(430)	348	(361)	199	(172)	68	(38.8)	20.7	(611)	251
	7.5 -15.0	186	237	302	281	253	230	54	66	29.6	19.4	241	264
	15.0 -22.5	219	230	229	226	201	243	21	75	26.8	20.3	153	257
	22.5 -30.0	239	191	146	211	103	149	24	26	13.4	14.0	57	162

STATISTICS ($LSD_{0.05}$)#

Soil Layer	Alkaline Phosphatase T	R	T by R	Acid Phosphatase T	R	T by R	Aryl-Sulfatase T	R	T by R	Invertase T	R	T by R	Amidase T	R	T by R	Urease T	R	T by R
0- 1.25		195			218			146			137			7.5			198	
1.25- 2.5		86			239			107			99			10.0			215	
2.5 - 5.0		68			114			120			99			11.8			143	
5.0 - 7.5		82			137			87			65			17.8			147	
0- 7.5	34	42	59	64	79	111	41	50	70	32	39	56	3.8	4.6	6.6	52	63	89
7.5 -15.0	41	50	71	43	53	75	34	42	59	13	16	23	5.9	5.9	10.2	49	60	85
15.0 -22.5	40	49	69	50	61	87	25	30	43	20	24	34	6.8	6.8	11.8	31	38	53
22.5 -30.0	44	54	76	56	69	98	28	34	48	12	15	22	4.6	4.6	8.0	22	27	37

† 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 of 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 layers.
# Least significant difference (LSD) values are given for the main effects of tillage (T) and rotation (R) and the interaction effect of tillage by rotation (T by R)

nificantly lower in the NT plots. The differences in the distribution of soil parameters within the profile can be attributed to applying the majority of fertilizers as a broadcast application without mechanical incorporations for the NT treatment and the uptake of nutrients from the subsoil that are incorporated into the plant and then subsequently deposited on the soil surface as plant residue. The increased enzyme activities in the surface layer of the NT soil profile suggest that repeated applications of herbicides and insecticides to the NT plots without their incorporation by tillage operations to dilute their concentration throughout the soil profile does not cause any adverse biological effects.

LITERATURE CITED

1. Allison, L. E. 1965. Organic carbon. *In* C. A. Black et al. (ed.), Methods of Soil Analysis, Part 2. Agronomy 9:1367-1378, Am. Soc. of Agron., Madison, Wisconsin
2. Chapman, H. D. 1965. Cation exchange capacity. *In* C. A. Black et al. (ed.), Methods of Soil Analysis, Part 2. Agronomy 9:891-901, Am. Soc. of Agron., Madison, Wisconsin.
3. Conservation Tillage News. February, 1985. National Association of Conservation Districts, Conservation Tillage Information Center, Fort Wayne, Indiana.
4. Day, P. R. 1965. Particle fractionation and particle-size analysis. *In* C. A. Black et al. (ed.), Methods of Soil Analysis, Part 1. Agronomy 9:545-567, Am. Soc. of Agron., Madison, Wisconsin.
5. Dick, W. A. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. Soil Sci. Soc. Am. J. 47:102-107.
6. Dick, W. A. 1984. Influence of long-term tillage and crop rotation combinations on soil enzyme activities. Soil Sci. Soc. Am. J. 48:569-574.
7. Dick, W. A and D. M. Van Doren, Jr. 1985. Continuous tillage and rotation combinations effects on corn, soybean and oat yields Agron. J. 77:459-465.
8. Dick, W. A., D. M. Van Doren, Jr., G. B. Triplett, Jr. and J. E. Henry. 1986. Influence of long-term tillage and rotation combinations on crop yields and selected soil parameters. II. Results obtained for a Typic Fragiudalf soil. Research Bulletin No.1180 of The Ohio State University and The Ohio Agricultural Research and Development Center, Wooster, Ohio
9. Harvey, W. R. 1960. Least squares analysis of data with unequal subclass numbers. USDA, ARS 20-8, July 1960.
10. Ladewig, H. and R. Garibay. 1983. Reasons why Ohio farmers decide for or against conservation tillage. J. Soil Water Conservation 38:487-488.
11. Laflen, J. M., M. Amemiya, and E A. Hintz. 1981. Measuring crop residue cover. J. Soil Water Conserv. 36:341-343.
12. Leamer, R. W. and B. Shaw. 1941. A simple apparatus for measuring non-capillary porosity on an extensive scale. J. Amer. Soc. Agron. 33:1003-1008.
13. McLean, E. O. 1981. Soil pH and lime requirement. *In* A. L. Page, R. H. Miller, and D. R. Keeney (eds.), Methods of Soil Analysis, Part 2. Agronomy 9:199-224, Am. Soc. of Agron., Madison, Wisconsin.
14. Olsen, S. R. and L. A. Dean. 1965. Phosphorus. *In* C. A. Black et al. (ed.), Methods of Soil Analysis, Part 2. Agronomy 9:1035-1049, Am. Soc. of Agron., Madison, Wisconsin.
15. Richards, L. A. 1965. Physical condition of water in soil. *In* C. A. Black et al. (ed.), Methods of Soil Analysis, Part 1. Agronomy 9:128-152, Am. Soc. of Agron., Madison, Wisconsin.
16. Tiarks, A. E. 1977. Causes of increased corn root rot infection of continuous corn in no-tillage Hoytville clay loam in Northwestern Ohio. Ph.D. Thesis. Ohio State University. Univ. Microfilms. Ann Arbor, Mich. (Diss. Abstr. DCJ 77-17145).

APPENDIX

Table I. Average Monthly Mean Temperature Record.

Year	Mean Temperature During Month Indicated											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	°C											
1963	-8.8	-6.0	3.7	10.0	14.0	21.1	23.0	19.9	16.8	15.9	7.0	-6.4
1964	-1.6	-2.8	3.2	10.8	17.8	21.4	23.4	21.0	18.6	9.8	7.1	-0.9
1965	-2.6	-3.0	3.9	8.6	19.0	20.5	20.9	20.5	19.5	11.3	6.0	2.4
1966	-5.7	-2.2	4.6	8.6	12.7	21.6	23.4	20.8	16.6	10.1	6.0	0.2
1967	-0.6	-4.3	3.1	11.4	13.3	22.7	21.7	19.7	15.7	12.2	2.6	0.6
1968	-5.6	-3.9	4.6	11.4	14.2	21.6	22.6	22.2	18.8	12.3	6.0	-1.2
1969	-4.8	-1.8	2.0	11.1	16.3	20.1	23.2	22.2	18.0	12.0	3.4	-2.8
1970	-8.3	-2.5	1.1	9.7	18.3	21.4	22.7	21.8	20.2	13.2	4.8	-0.3
1971	-6.9	-2.0	1.7	8.7	14.6	22.3	21.3	20.1	19.3	15.7	4.3	1.3
1972	-3.8	-2.8	2.1	8.1	16.3	17.7	21.9	20.3	17.3	8.7	3.4	-1.1
1973	-1.7	-3.4	6.7	9.1	13.1	21.7	22.8	22.1	19.0	13.3	6.2	-2.3
1974	-3.9	-4.5	2.7	9.8	13.4	19.3	22.7	21.6	15.7	9.3	5.3	-1.8
1975	-1.5	-2.6	0.7	5.1	17.6	20.7	21.8	22.2	14.6	11.4	7.8	-0.9
1976	-6.3	0.6	5.2	10.0	13.6	21.4	21.9	19.3	15.7	7.6	0.4	-6.2
1977	-13.1	-4.5	5.4	11.2	18.1	19.2	23.2	20.5	18.1	9.5	5.3	-3.8
1978	-8.4	-12.3	2.7	8.0	14.5	20.6	21.8	21.4	19.9	9.9	5.3	-1.6
1979	-7.7	-9.9	3.7	8.1	14.4	20.5	21.2	20.3	17.1	10.9	5.2	0.1
1980	-3.8	-6.3	-0.1	8.5	15.2	19.1	22.7	23.2	18.2	8.5	3.1	-2.3
1981	-8.4	-1.9	2.4	10.0	13.2	20.0	22.3	21.2	16.5	9.0	4.8	-2.4
1982	-8.8	-6.8	1.3	6.3	18.8	18.7	22.4	19.8	16.9	12.0	5.9	3.3
1983	-2.6	-0.2	3.9	7.2	12.9	20.6	24.2	23.3	17.9	11.4	6.2	-5.6
1984	-8.4	0.7	-2.8	8.6	13.1	22.4	21.2	21.7	16.3	13.1	3.7	1.6
22-yr avg.	-5.6	-3.7	2.8	9.1	15.2	20.7	22.4	21.2	17.6	11.2	5.0	-1.4

Table II. Total Monthly Precipitation Record†.

Year	Precipitation During Month Indicated												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
	mm												
1963	17	13	71	83	67	54	122	105	21	1	52	12	618
1964	44	12	102	150	54	58	40	76	45	14	24	59	678
1965	115	83	55	82	66	117	50	133	84	94	40	58	977
1966	21	29	44	89	87	88	123	105	72	38	162	110	968
1967	19	40	37	66	109	44	130	64	74	61	70	110	824
1968	59	20	48	73	104	84	40	53	43	34	87	82	727
1969	95	6	38	83	112	104	35	34	120	64	86	53	830
1970	28	20	56	136	69	79	137	19	77	52	56	41	770
1971	32	57	23	24	101	136	160	23	108	39	42	101	846
1972	9	13	72	80	81	89	163	162	154	41	120	103	1087
1973	34	20	122	68	118	173	88	24	18	83	71	71	890
1974	94	39	105	72	105	70	7	74	38	18	70	51	743
1975	55	13	49	41	131	91	45	232	98	54	38	65	912
1976	57	72	75	50	88	42	96	50	80	52	5	12	679
1977	11	59	96	92	60	55	149	98	132	51	50	91	944
1978	30	13	69	111	91	74	38	49	51	45	47	40	658
1979	43	36	45	117	107	126	90	183	42	33	104	61	987
1980	22	19	102	68	75	98	158	191	61	35	25	28	882
1981	9	62	17	104	84	173	34	89	87	119	34	65	977
1982	71	46	87	26	89	90	109	12	46	5	157	93	831
1983	16	11	45	89	101	91	105	37	63	123	170	93	944
1984	19	31	44	145	133	28	87	112	59	42	61	67	828
22-yr avg	41	32	64	84	92	94	91	88	72	50	71	67	845

† 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
		mt ha^{-1}	kg ha^{-1}					
CC	1963		168			13	54	27
	1964		168			22	89	44
	1965		168			13	54	27
	1966		188			11	45	45
	1967		188	112	112	11	45	45
	1968		225	78	145	6	22	22
	1969	9 0	225	78	78	6	22	22
	1970		320	78	78	6	22	22
	1971		300	73	73	6	22	22
	1972		338	87	87	6	22	22
	1973		265	109	109	6	22	22
	1974		246	87	87	9	38	38
	1975		267	67	67	7	27	27
	1976		267	87	87	7	27	27
	1977		252	73	73	7	27	27
	1978	2 3	300	87	87	7	27	27
	1979		290	87	87	7	27	27
	1980		300	87	87	7	27	27
	1981		295	87	87	9	40	40
	1982		370	87	272			
	1983		370	87	87			
	1984	5 7	333	87	87	20	40	40
CS‡	1963		168(c)§			13(c)	54(c),45(s)	27(c),22(s)
	1964		168(c)			22(c)	89(c),45(s)	44(c),45(s)
	1965		168(c)			13(c)	54(c),45(s)	27(c),45(s)
	1966		188(c)			11(c)	45(c,s)	45(c,s)
	1967		188(c)	112(c,s)	112(c,s)	11(c)	45(c,s)	45(c,s)
	1968		225(c)	78(c,s)	145(c),78(s)	6(c,s)	22(c,s)	22(c,s)
	1969	9 0(c,s)	225(c)	78(c,s)	78(c,s)	6(c,s)	22(c,s)	22(c,s)
	1970		320(c)	78(c,s)	78(c,s)	6(c,s)	22(c,s)	22(c,s)
	1971		300(c)	73(c,s)	73(c,s)	6(c,s)	22(c,s)	22(c,s)
	1972		338(c)	87(c,s)	87(c,s)	6(c,s)	22(c,s)	22(c,s)
	1973		265(c)	109(c,s)	109(c,s)	6(c,s)	22(c,s)	22(c,s)
	1974		246(c)	87(c,s)	87(c,s)	9(c),7(s)	38(c),27(s)	38(c),27(s)
	1975		267(c),17(s)	67(c,s)	67(c,s)	7(c,s)	27(c,s)	27(c,s)
	1976		267(c)	87(c,s)	87(c,s)	7(c)	27(c)	27(c)
	1977		252(c)	73(c,s)	73(c,s)	7(c,s)	27(c,s)	27(c,s)
	1978	2 3(c,s)	330(c)	87(c,s)	87(c,s)	7(c)	27(c)	27(c)
	1979		290(c)	87(c,s)	87(c,s)	7(c)	27(c)	27(c)
	1980		300(c)	87(c,s)	87(c,s)	7(c,s)	27(c,s)	27(c,s)
	1981		295(c)	87(c,s)	87(c,s)	9(c),5(s)	40(c),20(s)	40(c),20(s)
	1982		370(c)	87(c,s)	272(c,s)			
	1983		370(c)	87(c,s)	87(c,s)			
	1984	5 7(c,s)	333(c)	87(c,s)	87(c,s)	20(c,s)	40(c,s)	40(c,s)

(Continued)

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

Rotation†	Year	Broadcast				Row		
		Lime	N	P_2O_5	K_2O	N	P_2O_5	K_2O
		mt ha^{-1}	kg ha^{-1}					
COM	1963		168(c)			13(c),27(o)	54(c,o)	27(c,o)
	1964		168(c)			22(c),13(o),14(m)	89(c),76(o),56(m)	44(c),49(o),56(m)
	1965		168(c)			13(c,o)	54(c,o)	27(c,o)
	1966		188(c)			11(c),13(o)	45(c),54(o)	45(c),17(o)
	1967		188(c)	112(c,o,m)	112(c,o,m)	11(c),13(o)	45(c),54(o)	45(c),27(o)
	1968		225(c),19(o),38(m)	78(c,o,m)	145(c,m),78(o)	6(c,o)	22(c,o)	22(c,o)
	1969	9 0(c,o,m)	225(c),38(o)	78(c,o,m)	78(c,o,m)	6(c,o)	22(c,o)	22(c,o)
	1970		320(c),47(o)	78(c,o,m)	78(c,o,m)	6(c,o)	22(c,o)	22(c,o)
	1971		300(c),56(o)	73(c,o,m)	73(c,o,m)	6(c,o)	22(c,o)	22(c,o)
	1972		338(c),56(o)	87(c,o,m)	87(c,o,m)	6(c),11(o)	22(c),45(o)	22(c),45(o)
	1973		265(c),56(o)	109(c,o,m)	45(c,o,m)	6(c)	22(c)	22(c)
	1974		246(c),50(o,m)	87(c,o,m)	87(c,o,m)	9(c,o)	38(c,o)	38(c,o)
	1975		267(c),67(o),17(m)	67(c,o,m)	67(c,o,m)	7(c),25(o)	27(c),25(o)	27(c),25(o)
	1976		267(c),67(o)	87(c,o,m)	87(c,o,m)	7(c,o)	27(c),54(o,m)	27(c),45(o,m)
	1977		252(c),70(o)	73(c,o,m)	73(c,o,m)	7(c,o)	27(c,o)	27(c,o)
	1978	2 3(c,o,m)	300(c),63(o,m)	87(c,o,m)	87(c,o,m)	7(c),10(o)	27(c),40(o)	27(c),40(o)
	1979		290(c),66(o,m)	87(c,o,m)	87(c,o,m)	7(c),8(o)	27(c),34(o)	27(c),34(o)
	1980		300(c),53(o),150(m)	87(c,o,m)	87(c,o,m)	7(c),75(o),25(m)	27(c),75(o),25(m)	27(c),75(o),25(m)
	1981		295(c),63(o,m)	87(c,o,m)	87(c,o,m)	9(c),33(o)	40(c),87(o)	40(c),87(o)
	1982		370(c),55(o),150(m)	87(c,o,m)	272(c,o,m)			
	1983		370(c),55(o),75(m)	87(c,o,m)	87(c,o,m)			
	1984	5 7(c,o,m)	333(c),55(o)	87(c,o,m)	87(c,o,m)	20(c)	40(c)	40(c)

† CC, continuous corn, CS, corn and soybeans in a two-year rotation, and COM, corn, oats, and meadow in a three-year rotation
‡ Approximately 3 4 kg ha^{-1} of Mn (elemental basis) was applied to the soybean crop as a foliar spray each year
§ The lower case letter in parentheses indicates the crop within the rotation to which the fertilizer was applied

Table IV. Herbicide and Insecticide Materials and Rates Applied.

Rotation†	Year	Herbicide and Insecticide Applied to Tillage System Specified‡		
		No-Tillage (NT)	Minimum Tillage (MT)	Conventional Tillage (CT)
		kg active ingredients ha^{-1}		
CC	1963	3.4-At,1.1-2,4-D,4.5-AmT	3.4-At	same as MT
	1964	2.2-At,3.4-AmT,1.1-Lox	same as NT	same as NT
	1965	2.2-At,1.1-Lox,2.2-AmT	same as NT	same as NT
	1966	2.2-At,4.5-AmT,1.1-Lox	same as NT	same as NT
	1967	1.1-At,1.1-Lox,0.8-BanD,0.6-P,0.6-2,4-D	same as NT	same as NT
	1968	1.1-At,1.1-Lox,1.4-2,4-D,0.6-Sim,0.3-BanD,2.8-Cl	same as NT	same as NT
	1969	1.1-At,1.1-Lox,1.1-Sim,1.7-2,4-D,1.1-P,1.6-Diaz	same as NT minus 1.1-P	same as MT
	1970	1.1-At,1.1-Lox,1.1-Sim,0.6,P,0.6-BanD,1.6-Diaz	same as NT	same as NT
	1971	1.1-At,1.1-Lox,1.1-Sim,0.6-P,0.6-BanD,2.2-Las,1.1-2,4-D,1.1-F	same as NT	same as NT
	1972	2.2-At,2.2-Las,0.6-BanD,1.7-2,4-D,1.1-Bx	same as NT	same as NT
	1973	2.2-At,2.2-Las,0.6-BanD,0.6-2,4-D,1.1-F	same as NT	same as NT
	1974	3.3-At,2.2-Las,0.3-BanD,1.4-2,4-D,1.1-F	same as NT minus 1.1-At	same as MT
	1975	1.1-At,3.4-Las,0.6-P,1.1-Sim,0.6-BanD,2.8-Cl	same as NT	same as NT
	1976	2.2-At,2.2-Las,0.3-BanD,1.4-2,4-D,1.1-F	same as NT	same as NT
	1977	2.5-At,2.2-Las,0.3-BanD,2.2-R,0.6-2,4-D,1.1-F	same as NT	same as NT
	1978	2.2-At,2.2-Las,2.2-R,0.6-2,4-D,1.1-F	same as NT	same as NT
	1979	2.2-At,2.2-Las,1.7-R,1.1-B,1.7-C	same as NT	same as NT
	1980	2.2-At,2.8-Bl,1.7-R,1.1-B,1.7-C	same as NT	same as NT
	1981	1.1-F,1.4-Sim,1.7-Bl,0.6-R,1.1-Sev,1.1-B	same as NT	same as NT
	1982	1.1-C,1.1-At,3.3-Las,0.6-P,6.6-Tox,0.6-B	same as NT	same as NT
	1983	1.1-Amz,2.8-Bl,3.3-Las,1.7-R,2.8-Tox	same as NT	same as NT
	1984	1.5-C,1.1-R,1.7-At,2.2-Bl,2.2-Las,1.1-B	same as NT	same as NT
CS	1963	corn same as for CC,3.4-Am(s)§,4.5-D(s)	3.4-At(c),3.4-Am(s)	same as MT
	1964	corn same as for CC,1.1-Lox(s),3.4-Am(s)	same as NT	same as NT
	1965	corn same as for CC,1.1-Lox(s),3.4-Am(s),3.4-AmT(s)	same as NT	same as NT
	1966	corn same as for CC,4.5-AmT(s),0.6-2,4-DB(s),4.5-Am(s)	same as NT	same as NT
	1967	corn same as for CC,3.4-Am(s),3.4-AmT(s),1.1-Lox(s)	same as NT	same as NT
	1968	corn same as for CC,3.4-AmT(s),2.2-ClPC(s)	same as NT	same as NT
	1969	corn same as for CC,3.9-AmT(s),2.2-ClPC(s),2.2-Am(S),0.6-2,4-D(s)	same as NT	same as NT
	1970	corn same as for CC,2.2-AmT(s),2.2-ClPC(s),3.4-Am(s)	same as NT	same as NT
	1971	corn at 2/3 rate as CC,1.2-F(c),1.5-Las(s),3.4-Am(s),2.2-ClPC(s),1.1-P(s)	same as NT	same as NT
	1972	corn same as for CC,3.4-Am(s),2.2-ClPC(s),2.2-Las(s),2.2-AmT(s)	same as NT	same as NT
	1973	corn same as for CC,3.4-Am(s),2.2-Las(s),0.6-2,4-D(s),1.7-B(s)	same as NT	same as NT
	1974	corn same as for CC minus 1.1-At,3.4-Am(s),2.2-ClPC(s),2.2-Las(s),0.6-2,4-D(s)	same as NT	same as NT
	1975	corn same as for CC,0.6-Sen(s),2.5-Las(s),2.2-R(s)	same as NT	same as NT
	1976	corn same as for CC,0.6-Sen(s),2.2-Las(s),2.2-R(s),1.1-B(s)	same as NT	same as NT
	1977	corn same as for CC,0.3-Sen(s),2.2-Las(s),2.2-R(s)	same as NT	same as NT
	1978	corn same as for CC,0.4-Sen(s),2.2-Las(s),2.2-R(s),1.1-B(s),1.1-H(s)	same as NT	same as NT
	1979	corn same as for CC,0.8-Sen(s),2.5-Las(s),3.3-R(s),1.1-B(s)	same as NT	same as NT
	1980	corn same as for CC,0.6-Sen(s),2.2-Las(s),1.7-R(s),1.1-B(s)	same as NT	same as NT
	1981	corn same as for CC,0.6-Sen(s),5.5-Las(s),1.1-B(s)	same as NT	same as NT

(Continued)

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

Rotation†	Year	Herbicide and Insecticide Applied to Tillage System Specified‡		
		No-Tillage (NT)	Minimum Tillage (MT)	Conventional Tillage (CT)
		kg active ingredients ha⁻¹		
CS	1982	corn same as for CC,0.6-Sen(s),3.3-Las(s),0.6-P(s),0.8-B(s)	same as NT	same as NT
	1983	corn same as for CC,0.5-Sen(s),3.3-Las(s),1.7-R(s),1.1-B(s)	same as NT	same as NT
	1984	corn same as for CC,0.5-Sen(s),2.2-Las(s),2.0-Am(s),1.1-B(s)	same as NT	same as NT
COM	1963	3.4-At(c),1.1-2,4-D(c),4.5-Dal(c),4.5-AmT(c)	3.4-At(c)	same as MT
	1964	2.2-At(c),7.8-AmT(c),1.1-Lox(c)	2.2-At(c),3.4-AmT(c),1.1-Lox(c)	same as MT
	1965	5.6-At(c),6.7-AmT(c),1.1-Lox(c)	2.2-At(c),2.2-AmT(c),1.1-Lox(c)	same as MT
	1966	5 6-At(c),1.1-Lox(c),9.0-AmT(c),1.1-2,4-DB(m),2.2-Dal(o)	corn same as for CC,2.2-Dal(o),0.9-2,4-DB(o,m)	same as MT
	1967	corn as for CC plus 4.5-AmT(c),1.1-P(m)	corn same as for CC,1.1-P(m)	same as MT
	1968	corn as for CC plus 4.5-AmT(c),1.1-2,4-D(m),4.5-Dal(m)	corn same as for CC,1.1-2,4-D(m),4.5-Dal(m)	same as MT
	1969	corn same as for CC,4.5-Dal(m),1.1-2,4-D(m)	corn same as for CC,1.1-2,4-D(m),4.5-Dal(m)	same as MT
	1970	corn same as for CC,4.5-Dal(m),1.1-2,4-D(m)	same as NT	same as NT
	1971	corn as for CC plus 1 1-2,4-D(c),6.7-Dal(m),1.7-2,4-D(m)	corn same as for CC,4.5-Dal(m)1.1-2,4-D(m)	same as MT
	1972	corn same as for CC,4.5-AmT(m)	same as NT	same as NT
	1973	corn same as for CC	same as NT	same as NT
	1974	corn same as for CC plus 1.7-R(c),2.2-R(m)	corn same as for CC,2.2-R(m)	same as MT
	1975	corn same as for CC,2.2-AmT(m)	same as NT	same as NT
	1976	corn same as for CC,2.2-R(m)	same as NT	same as NT
	1977	corn same as for CC,2.2-R(m)	same as NT	same as NT
	1978	corn same as for CC,2.2-R(m)	same as NT	same as NT
	1979	corn same as for CC,2.2-R(m)	same as NT	same as NT
	1980	corn same as for CC,2.2-R(o,m)	same as NT	same as NT
	1981	corn same as for CC,0.6-2,4-D(o,m)	same as NT	same as NT
	1982	corn same as for CC,1.1-B(m)	same as NT	same as NT
	1983	corn same as for CC	same as NT	same as NT
	1984	corn same as for CC,1 1-2,4-D(m),0.5-BanD(m)	same as NT	same as NT

† 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

At = Atrazine	B = Basagran	Cl = Chlordane	F = Furadan	P = Paraquat	Sev = Sevin
Am = Amiben	Bl = Bladex	ClPC = CIPC	H = Hoelon	R = Roundup	Tox - Toxaphene
AmT = Amitrole	Bx = Bux	Dal = Dalapon	Las = Lasso	Sim = Simazine	2,4-D = 2,4-D
Amz = Amaze	C = Counter	Diaz = Diazinon	Lox = Lorox	Sen = Sencor	2,4-DB = 2,4-DB
BanD = Banvel D					

§ The lower case letter in parentheses indicates the crop within the rotation to which the herbicide 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-methylpropionnitrile
CIPC (chlorpropham)	1-methyethyl 3-chlorophenyl carbamate
Dalapon	2,2-dichloropropanoic acid
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
2,4-D	2,4-dichlorophenoxy acetic acid
2,4-DB	4-(2,4-dichlorophenoxy) butyric acid
Insecticides:	
Amaze (isofenphos)	1-methylethyl-2-((ethoxy)(1-methylethyl)amino)phosphinothioyl)oxy)benzoate
Bux (bufencarb)	1:3 ratio of *m*-(ethylpropyl)phenyl methylcarbamate and *m*-(1-methylbutyl)phenyl methylcarbamate
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
Diazinon	*0,0*-diethyl *0*-(2-isopropyl-4-methyl-6-pyrimidinyl)-phosphorothioate
Furadan (carbofuran)	2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate
Sevin (carbaryl)	1-naphthyl N-methylcarbamate
Toxaphene	chlorinated camphene

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}		
1964	CC	42.0	40.2	39.0
	CS	42.5	42.0	40.0
	COM	40.7	38.0	40.0
1965	CC	43.5	54.3	58.3
	CS	46.4	57.0	58.3
	COM	46.7	50.1	53.5
1966	CC	45.2	44.7	51.9
	CS	48.9	51.1	47.4
	COM	49.1	43.7	50.6
1967	CC	46.8	46.5	52.0
	CS	38.1	48.7	49.1
	COM	37.8	49.6	50.9
1968	CC	68.1	66.2	67.7
	CS	70.0	66.3	66.3
	COM	64.9	63.0	63.5
1969	CC	62.6	65.7	67.8
	CS	66.9	66.0	67.3
	COM	65.8	67.0	64.1

(Continued)

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} ----------		
1970	CC	51.1	46.4	49.4
	CS	49.9	56.1	48.0
	COM	49.7	57.4	59.6
1971	CC	49.4	53.7	56.0
	CS	55.2	57.3	57.8
	COM	50.4	55.8	56.7
1972	CC	46.9	45.5	52.7
	CS	49.1	52 1	52.4
	COM	46.5	50.5	48.5
1973	CC	38.3	39.8	48.1
	CS	33.7	48.7	44.0
	COM	41.8	42.1	44.9
1974	CC	57.2	64.2	69.1
	CS	65.8	61.9	65.5
	COM	57.5	64.4	63.6
1975	CC	61.9	65.9	67.2
	CS	62.4	67.6	67.2
	COM	63.4	69.1	69.4
1976	CC	53.0	55.8	57.2
	CS	56.2	56.6	54.4
	COM	49.1	58.5	58.6
1977	CC	50.0	47.2	52.3
	CS	40.6	50.8	50.9
	COM	43.9	50.0	57.5
1978	CC	57.1	56.3	56.9
	CS	63.9	56.7	58.4
	COM	60.9	64.0	61.1
1979	CC	51.3	65.7	62.0
	CS	61.6	63.5	64.3
	COM	56.3	63.6	65.3
1980	CC	36.2	45.0	52.3
	CS	51.4	48.7	53.6
	COM	48.7	48.4	52.4
1982	CC	66.3	59.6	64.7
	CS	69.2	60.8	66.3
	COM	55.4	56.4	62.5
1983	CC	73.2	77.5	76.2
	CS	75.5	78.2	75.9
	COM	60.8	73.4	74.9
1984	CC	59.7	53.8	61.2
	CS	50.2	59.2	56.9
	COM	52.8	56.5	59.7

† Emergence data were not recorded for crop years 1963 and 1981.
‡ 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 VII. Planting and Harvest Dates for Oats, Corn, and Soybeans.

Year	Planting Date			Harvest Date		
	Oats	Corn	Soybeans	Oats	Corn	Soybeans
1963	Apr 9	May 8	May 24	-‡	Nov 25	Oct 10
1964	Apr 14	May 19	May 19	Jul 20	Oct 30	Sep 29
1965	Apr 8	May 14	Jun 1	Jul 21	Nov 18	Oct 13
1966	Mar 17	May 31	May 31	Jul 26	Nov 1	Oct 5
1967	Apr 18	May 23	Jun 10	Aug 4	Nov 9	Oct 24
1968	Mar 8	Apr 26	Jun 7	Jul 17	Oct 30	Oct 2
1969	Mar 5	May 5	May 30	Jul 23	Nov 10	Oct 23
1970	Apr 10	May 7	May 27	Jul 22	Nov 11	Oct 5
1971	Mar 29	Apr 22	May 5	Jul 28	Oct 14	Oct 5
1972	Mar 29	May 3	May 22	Jul 26	Oct 25	Oct 10
1973	Apr 16	Apr 27	Jun 2	Jul 30	Oct 11	Oct 8
1974	Apr 3	Apr 26	May 2	Jul 25	Oct 10	Oct 1
1975	Apr 2	May 2	May 19	Jul 17	Oct 22,28	Oct 7
1976	Mar 24	Apr 16	May 20	Jul 13	Oct 18,22	Oct 5
1977	Apr 1	May 13	May 13	Jul 20	Oct 13	Oct 4
1978	Apr 17	May 2	May 8	Jul 30	Oct 17	Oct 11
1979	Apr 19	Apr 23	May 8 (Jul 3)†	Aug 13	Oct 26	Oct 18
1980	Apr 22	Apr 23	May 2	Jul 25	Oct 27	Sep 27
1981	Mar 18	May 8 (Jul 7)†	May 21 (Jul 6)†	Jul 23	Nov 13	Oct 7
1982	Apr 22	Apr 23	Apr 29	Aug 4	Oct 13	Sep 22
1983	Mar 4	May 18	May 18	Jul 26	Oct 28	Sep 26,30
1984	Apr 12	May 14	May 14	Aug 31	Oct 31	Oct 17

† The 1979 soybean crop and many of the individual 1981 corn and soybean plots were replanted due to hail and flood damage, respectively.
‡ Oats were destroyed in the process of killing weeds and no yield data were obtained.

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}		
1963	CC	Plots thinned to a common population which was not recorded.			7.34	6.96§	7.28
	CS				6.96	7.84	7.15
	COM				7.15	7.65§	7.53
1964	CC	38.3	34.5	34.3	4.56	4.77	4.68
	CS	35.0	35.2	37.1	5.02	5.25	5.21
	COM	34.5	35.5	35.9	4.66	5.10	5.04
1965	CC	39.8	41.7	40.5	6.27	7.17	6.75
	CS	41.7	42.5	43.2	7.02	7.61	7.78
	COM	41.5	41.7	41.0	7.25	6.71	7.46
1966	CC	45.7	45.9	49.4	5.58	6.71	6.77
	CS	46.2	46.9	45.2	6.96	6.71	7.15
	COM	45.9	45.7	45.2	6.59	6.84	6.40
1967	CC	46.7	46.4	52.1	7.53	8.09§	8.59
	CS	38.3	48.6	49.1	8.37	8.28	8.59
	COM	37.7	49.6	51.6	-††	8.66	9 41
1968	CC	56.5	58.5	60.0	4.83	5.83	6.00
	CS	58.3	60.7	58.5	6.46	6.21	5.71
	COM	60.0	61.5	64.2	6.27	6.02	5.90
1969	CC	62.7	65.9	68.1	4.70	5.83	5.83
	CS	67.2	66.7	67.4	6.33	6.46	6.27
	COM	65.9	67.2	64.4	6.02	5.96	6.08
1970	CC	48.6	48.6	48.6	6.15	7.71	7.09
	CS	48.6	48.6	48.6	6.59	7.97	7.90
	COM	48.6	48.6	48.6	7.02	7.71	7.34

(Continued)

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 ----------		
1971	CC	48.1	48.1	48.4	9.22	10.5	10.5
	CS	48.4	48 4	48.4	10.7	10 2	10.3
	COM	47.9	48.4	48.4	10.8§	11.0	10.8
1972	CC	46.7	45.4	47.4	7.28	9 53	9.35
	CS	42.0	47.7	47.7	8.72#	9.60	9.53
	COM	46.4	47 7	47.7	9.16	9.47	10.4
1973	CC	38.3	39.8	48.1	6.90§	6 52§	7.28§
	CS	33.6	48.6	44.0	7.65#	7.59#	5.36§
	COM	41.7	42.0	46.7	7.55§	7 71§	7 30
1974	CC	57 3	57.5	57.5	3.26	4.64	5.14
	CS	57.5	57.5	57.5	4.64	5.52	5.64
	COM	57.5	57.5	57.5	4.26	4.32	5.08
1975	CC	62 0	65.9	67 2	9.22	11.0	9.97
	CS	62.5	67.7	66.2	10.1	10.7	10.5
	COM	63.5	69.1	69.4	10.7	11.4	11.0
1976	CC	49 1	49.1	49.1	7.90	7.90	8.28
	CS	49 1	49.1	49.1	8.53	8.28	8.22
	COM	49.1	49.1	49.1	7.71	8.09	7.65
1977	CC	48 4	48.4	48.4	8.66	9.28§	9.22
	CS	48 4	48.4	48.4	8.47#	9.72	8.47
	COM	49.1	48.1	48.4	9.16#	9.72	8.66
1978	CC	57.0	58.3	57.8	5.58	7.71	7.53
	CS	64.7	59.8	59.8	8.03	8.34	8.40
	COM	61.0	64.0	61.2	7.71	7.65	7.97
1979	CC	64.7	64.2	64.4	-††	11.9	12.3
	CS	64.4	64.7	64.4	11.4	12.5	11.8
	COM	63.7	64.2	64.4	11.3	12.7	13.0
1980	CC	33.8	44.4	44.2	6.15	9.16	8.84
	CS	44.2	44.2	44.2	8.40	9.91	9.47
	COM	44.4	44.2	44.4	9.53	10.6	10.2
1981	CC	-††	52.1	48.6	-††	5.90	5.58
	CS	-	49.9	50.1	-	6.52	6.13
	COM	-	47.9	50.1	-	7.73	6.29
1982	CC	55.8	55.8	55.8	8.67	7.57	7.90
	CS	55.8	55.8	55.8	10.1	8.77	8.10
	COM	54.2	53.3	55.3	8.86	9.13	9.31
1983	CC	73.2	77.5	76.3	5.92	6.17	6.25
	CS	77.0	78.1	75.8	6.84	7.09	6.77
	COM	62.5	73.3	74.9	6.85#	6.90	7.15
1984	CC	53.6	55.6	53.6	12.7	11.9	12.4§
	CS	54.0	53.6	54.3	13.6	12.5	12.0
	COM	53.9	51.4	53.6	-††	-††	12.7

† 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.
§ Two plots out of three were harvested
# One plot out of three was harvested
†† Data not recorded due to excessive weed infestation, spraying error, or variable plant population.

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								
1963	2.11§	1.92§	2.12§	-------- no yields recorded‡ --------			-------- no yields recorded‡ --------		
1964	2.00	2.06	2.12	2.65	3 14	3.05	--------- no yields recorded ---------		
1965	2.20	2.01	1.79	3.69	4.41	4.12	4.5	6.8	6.3
1966	2.80	2.53	2.47	2.16	2.96	3.16	4.8	7.1	7.1
1967	0.72	1.15	1.64	2.47	2.11	2.09	-------- no yields recorded‡ --------		
1968	3.95	3.89	3 90	3.54	3.80§	3.91	3.3	4 5	4.0
1969	-------- no yields recorded‡ --------			2.34	2.30	2.35	4.3	4.5	4.0
1970	2.26	2.31	2.41	1.75	2.43	2.60	6.7	7.3	7.9
1971	2.78	3.15	3.18	2.22§	2.15	2.43	-------- no yields recorded‡ --------		
1972	1.90	2.46	2.30	2.72	3.30	3.39	--------- no yields recorded ---------		
1973	1.39	2.12	1.62	2.42	2.52	2.40	--------- no yields recorded ---------		
1974	1.88§	1.89§	2.16§	3.20	3.38	3.08	--------- no yields recorded ---------		
1975	2.77	3.13	2.82	2.03	2.77	2.66	--------- no yields recorded ---------		
1976	1.03	2.81	2.05	3.04	3 24	3.45	--------- no yields recorded ---------		
1977	2.26§	3.25	3.15	2.89	2.73	2.76	--------- no yields recorded ---------		
1978	2.19	2.23	2.41	1.20	1.28	2.02	--------- no yields recorded ---------		
1979	--------- hail destroyed crop ---------			--------- hail destroyed crop ---------			--------- no yields recorded ---------		
1980	1.93§	3.24§	3.22§	3.15	3.98	3.83	--------- no yields recorded ---------		
1981	2.07	2.31	2.28	2.07	2.89	2.72	--------- no yields recorded ---------		
1982	2.65	2.62	2.81	2.36	2.52	2.49	--------- no yields recorded ---------		
1983	3.25	3.09	3.23	2.49	3.08	2.65	--------- no yields recorded ---------		
1984	3.21	2.96	2.78	-------- no yields recorded‡ --------			10.9	11.5	3.3#

† NT, no-tillage, MT, minimum tillage, and CT, conventional tillage
†† Several years the soybean plots were split and planted to a *Phythophthora* resistant (tolerant) and a susceptible cultivar. Yields in this table are for the resistant cultivar only except for 1981 where the susceptible cultivar yield data are reported.
‡ Yields not recorded due to spraying error, excessive weed infestation, or poor plant establishment.
§ Two plots of three were harvested
# Yield is based on one less cutting than for the other tillage treatments.

Table X. Nutrient Composition of Corn Ear Leaves Sampled at 50% Silking.

Tillage†	Rotation‡	Year	N	P	K	Ca	Mg	Mn	Fe	Zn	B	Cu	Sr	Mo
			Concentration of Element Specified											
			%					mg kg^{-1}						
NT	CC	1966	2.62	-§	-	-	-	-	-	-	-	-	-	-
		1967	2.85	0.31	1.93	0.85	0.34	28	157	36	8	13	22	2.2
		1968	-	0.34	3.00	1.23	0.49	38	267	39	18	17	37	1.2
		1969	2.65	0.29	2.14	0.81	0.31	17	175	32	13	14	28	1.0
		1970	2.92	0.34	1.97	0.93	0.36	33	155	41	11	15	27	4.4
		1972	2.71	0.37	2.55	0.63	0.30	15	133	29	12	16	31	1.4
		1975	2.61	0.43	2.34	0.68	0.39	15	150	34	18	15	33	1.7
	CS	1966	2.61	-	-	-	-	-	-	-	-	-	-	-
		1967	2.91	0.31	1.91	0.83	0.33	26	170	38	8	14	21	2.1
		1968	-	0.31	3.15	1.04	0.31	85	264	37	17	18	43	0.8
		1969	2.62	0.31	2.15	0.95	0.50	20	200	36	13	16	31	1.6
		1970	3.23	0.32	1.94	0.84	0.33	22	139	35	10	14	27	1.7
		1972	2.84	0.43	2.24	0.87	0.41	20	183	36	21	20	31	1.7
		1975	2.51	0.41	2.18	0.71	0.43	15	150	32	17	15	32	1.9
	COM	1966	2.58	-	-	-	-	-	-	-	-	-	-	-
		1967	2.85	0.32	1.82	0.75	0.26	24	157	37	8	14	21	2.1
		1968	-	0.32	3.07	1.12	0.43	28	237	36	22	17	47	1.7
		1969	2.87	0.29	2.12	0.80	0.33	14	156	32	14	17	29	1.0
		1970	3.37	0.32	1.68	0.87	0.38	20	146	31	9	14	27	1.9
		1972	2.73	0.42	2.57	0.67	0.33	13	154	29	17	16	32	1.4
		1975	2.65	0.44	2.32	0.74	0.39	12	158	35	18	16	35	1.8
MT	CC	1966	2.63	-	-	-	-	-	-	-	-	-	-	-
		1967	2.88	0.29	1.86	0.69	0.23	24	163	38	8	13	18	1.9
		1968	-	0.32	3.66	1.04	0.32	30	263	36	24	16	38	1.0
		1969	2.56	0.27	2.10	0.85	0.32	19	147	30	12	13	27	0.8
		1970	3.07	0.33	1.89	0.87	0.32	27	165	37	10	14	27	2.2
		1972	2.62	0.47	2.61	0.84	0.34	20	182	33	19	19	36	1.7
		1975	2.63	0.45	2.49	0.75	0.40	16	168	34	19	16	33	1.9
	CS	1966	2.59	-	-	-	-	-	-	-	-	-	-	-
		1967	2.78	0.29	1.96	0.71	0.26	22	151	35	8	13	21	1.9
		1968	-	0.36	3.83	1.08	0.32	72	327	37	22	17	43	0.9
		1969	2.52	0.26	2.17	0.76	0.27	15	148	29	11	12	25	0 6
		1970	2.73	0.31	2.18	0.79	0.25	22	137	29	9	13	27	1.1
		1972	2.72	0.39	2.24	0.80	0.32	17	172	29	15	17	30	1 5
		1975	2.26	0.44	2.56	0.80	0.39	15	158	32	18	16	35	2.0

(Continued)

Table X. Nutrient Composition of Corn Ear Leaves Sampled at 50% Silking.
(Continued)

Tillage†	Rotation‡	Year	N	P	K	Ca	Mg	Mn	Fe	Zn	B	Cu	Sr	Mo
			Concentration of Element Specified											
			%					mg kg^{-1}						
	COM	1966	2.69	-§	-	-	-	-	-	-	-	-	-	-
		1967	2.82	0.28	2.00	0.70	0.26	21	154	37	8	14	16	1.9
		1968	-	0.30	3.42	1.17	0.36	30	224	31	22	16	51	0.8
		1969	2.70	0.30	2.56	0.82	0.29	18	163	33	13	16	29	0.8
		1970	2.92	0.30	2.11	0.78	0.27	21	142	32	10	13	28	1.5
		1972	2.87	0.42	2.40	0.76	0.34	17	177	31	15	17	31	1.5
		1975	2.45	0.37	2.44	0.63	0.35	12	142	29	13	17	32	1.6
CT	CC	1966	2.58	-	-	-	-	-	-	-	-	-	-	-
		1967	2.90	0.33	1.99	0.78	0.27	26	178	42	8	14	17	2.3
		1968	-	0.37	3.56	1.26	0.40	66	310	42	25	16	40	1.7
		1969	2.64	0.31	2.34	0.96	0.39	18	195	34	20	14	28	1.1
		1970	2.87	0.34	1.75	0.88	0.34	23	162	44	11	14	25	4.5
		1972	2.77	0.39	2.13	0.84	0.37	21	199	34	17	19	31	1.6
		1975	2.65	0.45	2.53	0.76	0.40	15	164	36	21	17	33	2.0
	CS	1966	2.59	-	-	-	-	-	-	-	-	-	-	-
		1967	2.79	0.33	1.86	0.81	0.29	26	171	37	8	13	16	2.2
		1968	-	0.34	3.74	1.07	0.32	31	290	36	23	16	41	0.9
		1969	2.55	0.24	2.31	0.76	0.30	15	135	26	15	12	28	0.6
		1970	3.00	0.40	1.89	1.10	0.36	32	189	55	13	17	28	7.8
		1972	2.68	0.39	2.53	0.77	0.33	19	171	29	26	17	34	1.5
		1975	2.58	0.38	2.34	0.67	0.35	10	140	30	18	14	33	1.7
	COM	1966	2.58	-	-	-	-	-	-	-	-	-	-	-
		1967	2.82	0.30	2.08	0.79	0.27	26	161	37	9	14	20	1.9
		1968	-	0.32	2.87	1.12	0.33	27	288	34	23	17	42	1.0
		1969	2.56	0.26	2.00	0.73	0.32	18	124	30	12	13	25	1.2
		1970	3.03	0.34	2.04	0.92	0.34	25	156	40	11	15	30	2.4
		1972	2.80	0.44	2.22	0.83	0.40	21	176	33	16	18	32	1.7
		1975	2.33	0.47	2.50	0.88	0.46	14	178	36	19	18	34	2.2

† 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.

The Ohio State University
Ohio Agricultural Research and Development Center