Proceedings of the Indiana Academy of Science
(1987) Volume 97 p. 477-488.

Interactions of Weather, Soils and Management on Corn Yields: A Case Study in Wabash County, Indiana—1983

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ABSTRACT

Interactions of Weather, Soils and Management on Corn Yields: A Case Study in Wabash County, Indiana—1983. It is often difficult to interpret the results of plot level research conducted on farm fields over areas and years. Analysis of data from a study of the effect of tillage system on corn (*Zea mays* L.) yields obtained by Wabash County farmers in 1983 initially suggested that the mean yields obtained differed significantly by tillage system. Precipitation in 1983 in Wabash County was highly variable, however, and much of the variation among the yields obtained from different farms and tillage systems appeared to follow patterns of moisture stress, an interaction between weather and soil conditions.

To evaluate the effect of moisture stress on corn for the different tillage treatments, soil and weather variables were combined to calculate the daily ratio of actual to potential evapotranspiration, ET/PET, using SIMBAL, a soil water balance simulation program which considers the effects of soil and drainage conditions. The daily ET/PET calculations were summed from 40 days before to 50 days after silk for each plot and included as a single variable, ΣET/PET, along with management variables in the statistical analysis. Tillage treatment differences were no longer highly significant in explaining mean yields after appropriately accounting for soil and precipitation differences among plots, although a no-till*stress interaction indicated that the effect of increasing moisture stress on yield changed with tillage system. While these results were obtained using only data from a single year, they indicate that weather and soil information has to be considered explicitly in the interpretation of farm level experiments.

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It is often difficult to extend the results of plot level research to production agriculture even though the research may have been conducted in different sites and over a period of years. To present mean research results from plot experiments without explicitly considering weather, soils, and management interactions under which the research was conducted may lead to flawed extension advisories and farmers to make erroneous management decisions.

Although the adoption of soil conservation tillage systems has been increasing, there is reluctance on the part of many farmers to make changes which may reduce crop yields. There is little doubt that no-till and ridge till systems do conserve soil and water (5), but their effects on crop yields have been variable. Results from research on crop yield response to soil conservation tillage systems in Indiana have varied, ranging from generally no effect or slight yield increases over those with conventional tillage methods in southern areas to yield decreases in northern areas, primarily because soil temperatures may be lower under conservation tillage systems than with conventional tillage (6). Major factors have been soil drainage and prior crop, i.e., a system such as no-till does well on well drained soils even in heavy residue while on poorly drained soils no-till doesn't compete in heavy residues. Yields for other reduced systems such as chisel and ridge till are commonly assumed to not be affected to any great extent. To evaluate conservation tillage methods, the farmer needs to know that little, if any, effect on yields can be expected as he moves from conventional to reduced tillage systems.

In this study we examined the effect of tillage system on corn (*Zea mays* L.) yields obtained by Wabash County farmers during 1983. Although preliminary analysis of the data suggested that yields differed significantly by tillage system, most of the significant variation among corn yields seemed to follow moisture stress patterns, an interaction between weather and soil conditions. The objective of this study was to evaluate the effects of mositure stress* tillage interactions on yield response.

The weather in Wabash County during 1983 was cool and wet early in the growing season becoming hotter and much drier than normal in July and August. At the Wabash cooperative National Weather Service station, which has a 1951-1980 normal based on continuous observations, April received 129% of the normal rainfall, May 171%, and June 117%. July and August received 74%, and 41% of normal rainfall, and temperatures averaged 1.9 and 2.6°C above normal, respectively (13). Wabash County corn yields averaged 4.9 Mg/ha compared to 7.2 in 1982 and 8.0 in 1986 (12). The individual plot data for this study were obtained through the cooperation of farmers in Wabash County, Indiana, and the USDA Soil Conservation Service (SCS) during 1983. The *Soil Survey of Wabash County, Indiana* (11) provided much of the background information on soils.

Methods and Materials

Primary data for this study were gathered in 78 plots located in farmers' fields. Plots within fields were chosen to be homogeneous and representative of a particular Indiana soil type by SCS soil scientists. Observations were made on soil texture, erosion class, slope, depth of root zone, and primary soil classification for each plot. Soil samples were taken for laboratory analysis from each plot during the fall of the year when the corn was harvested to obtain yield estimates. A weediness rating for each plot based on the procedure outlined in *The Field Crops IPM Scout Manual* (3) was assigned at the same time. The farmers also furnished information on the amount of fertilizer applied, planting date, crop sequence, pesticide usage, and method of tillage used. Rainfall data were measured for each field from April 4 through June 26, and for 12 locations in Wabash County through September 15. The daily precipitation record for each of the field locations was completed from that measured at the nearest of the 12 stations. A summary of the data for the more important variables is included in the appendix.

Data and Analysis

The corn yields on the plots ranged from 0.4 to 10.0 Mg/ha (7 to 160 bu/ac) during 1983. The mean corn yields by tillage system for 1983 are shown in table 1. The mean yields, as well as an analysis of variance of only the yield data, indicated that the ridge system had a distinct yield advantage over the no-till and conventional systems. Acceptance of these results without consideration of other inputs could lead to a conclusion that the ridge system is far superior to the other systems for the kind of weather patterns experienced in Wabash County during 1983.

TABLE 1. Means of individual plot data for corn by tillage system.

	Conventional	Ridge till	No-till
	............previous	crop—corn	----------------
Observations	16	7	9
Yield (Mg/ha)	3.4	6.2	3.4
Stress	25.2	20.4	30.7
Nitrogen (kg/ha)#	166.2	190.3	202.4
Phosphorous (kg/ha)&	127.5	125.3	137.6
	————previous	crop—soybeans	----------------
Observations	9	16	21
Yield (Mg/ha)	4.2	5.6	4.5
Stress	27.3	25.0	27.1
Nitrogen (kg/ha)#	200.1	233.4	192.4
Phosphorous (kg/ha)&	141.5	131.2	158.6

Nitrogen applied; plot application increased by 22.4 kg/ha for corn in rotation with soybeans to account for nitrogen fixation of the legume crop.
& Available phosphorous based on soil test results.

Many other factors, however, interact to affect corn yield. These factors include rainfall received, solar radiation, potential evapotranspiration, soil water holding capacities, natural drainage conditions, fertilizer application rates, cropping sequence, and planting data. The yields reported in table 1 are not adjusted for the influence of any of these factors. Because of the summer heat and lack of rainfall during 1983, moisture stress was suspected to be the most limiting factor in determining corn yields and the principal cause of the variability in final yields observed among plots.

Variables affecting corn moisture stress include soil water holding capacity in the corn root zone, rainfall, potential evapotranspiration, and corn development. The program, SIMBAL, SIMulation of soil water BALance on poorly-drained and well-drained soils (1, 2, 10), was used to incorporate soil and daily weather information over the growing season into a single measure of plant stress. Moisture stress is defined as [1 - ET/PET] where ET is the actual plant evapotranspiration and PET is potential evapotranspiration, a measure of the atmospheric evaporative demand. ET depends both on the plant-available soil water supply and PET. If soil moisture is not limiting, ET is equal to PET (1 - ET/PET = 0), and the corn plant experiences no moisture stress. If ET is less than PET, the corn plant suffers moisture stress. Moisture stress was calculated daily for the entire growing season for each farm plot with SIMBAL.

Using an energy-crop growth variable which includes ET/PET, (7) found the period most highly correlated with final corn yield from 40 days before (and including) silking to 50 days after. Therefore, the variable used to identify mositure stress was the summation of the daily (1 - ET/PET)for this 90-day period for each corn plot.

Because potential evapotranspiration is relatively stable from year to year, precipitation and plant-available soil water holding capacity (WHC) are usually the two most important variables in determining moisture stress. The problem with evaluating tillage (or any management system) without considering spatial variability is demonstrated visually in figures 1 and 2. Three categories of WHC, total summer precipitation, and the 90-day moisture stress summed for each plot are shown in figure 1. We should point out that the "high, medium, and low" groupings for precipitation in figure 1 are relative to the 1983 average precipitation measured at various locations which, at the Wabash weather station, was about 78% of normal. Although there is considerable spatial variability in the data as reflected on the maps, note that during 1983 the patterns of total precipitation and WHC were similar, a random occurrence which tended to increase the range of moisture stress and corn yields between soils with lower and higher WHC. We should also point out that it is the distribution of the precipitation during the summer which is important for corn yield, not just the total. The distribution of precipitation is considered in the 90-day stress summation.

The three tillage systems used by farmers on the individual plots and three classes of final corn yields are plotted in figure 2. As with precipitation, the "high, medium, and low" yield classes are relative to 1983 and were considerably below normal as previously indicated. The tillage systems evaluated were conventional, ridge till and no-till. The conventional system is broadly defined and includes both moldboard plowing and chisel plowing followed by disking in the spring; the ridge till and no-till definitions are for standard practices (4). Some spatial groupings of tillage systems occur by soils. The ridge system tends to be used on soils with high WHC and poor drainage while the no-till system tends to be used on well-drained soils with lower WHC, both observations in accord with university recommendations.

The tendency for the weather and soil variability to confound the tillage treatment interpretations is demonstrated visually in figures 1 and 2 by the dashed lines marking three groups of selected plots, one for each tillage treatment. The no-till group is A (4 plots), B is a group of ridge till plots (7 plots), and C is two plots with conventional tillage. For A, the circled no-till plots (figure 2) generally have low WHC, "medium" precipitation, and high stress (figure 1), leading to low yields (figure 2). The circled ridge till plots (group B) had high WHC, "high" precipitation, and low stress which led to "high" yields in figure 2 and certainly contributed to the "significant" ridge till yield performance in table 1. For group C, the conventional tillage plots had low to medium WHC and precipitation, high stress, and resulting low corn yields.

The plot means for stress summation, nitrogen fertilizer applied, and available soil phosphorous are also listed in table 1 by tillage system. Mean moisture stress is lower for the ridge plots than the other tillage plots as indicated in figures 1 and 2. Based on Purdue Soil Testing Laboratory recommendations (9), fertilizer nitrogen rates for plots where the previous crop was soybeans were adjusted upwards by 22.4 kg/ha (20 lbs/ac) to account for the nitrogen fixation of the preceding soybean crop. There is no distinct relationship between either nitrogen or phosphorous and tillage system.

Linear regression techniques were used to correct for differences in inputs among plots by estimating quadratic response functions for corn yield. Independent variables

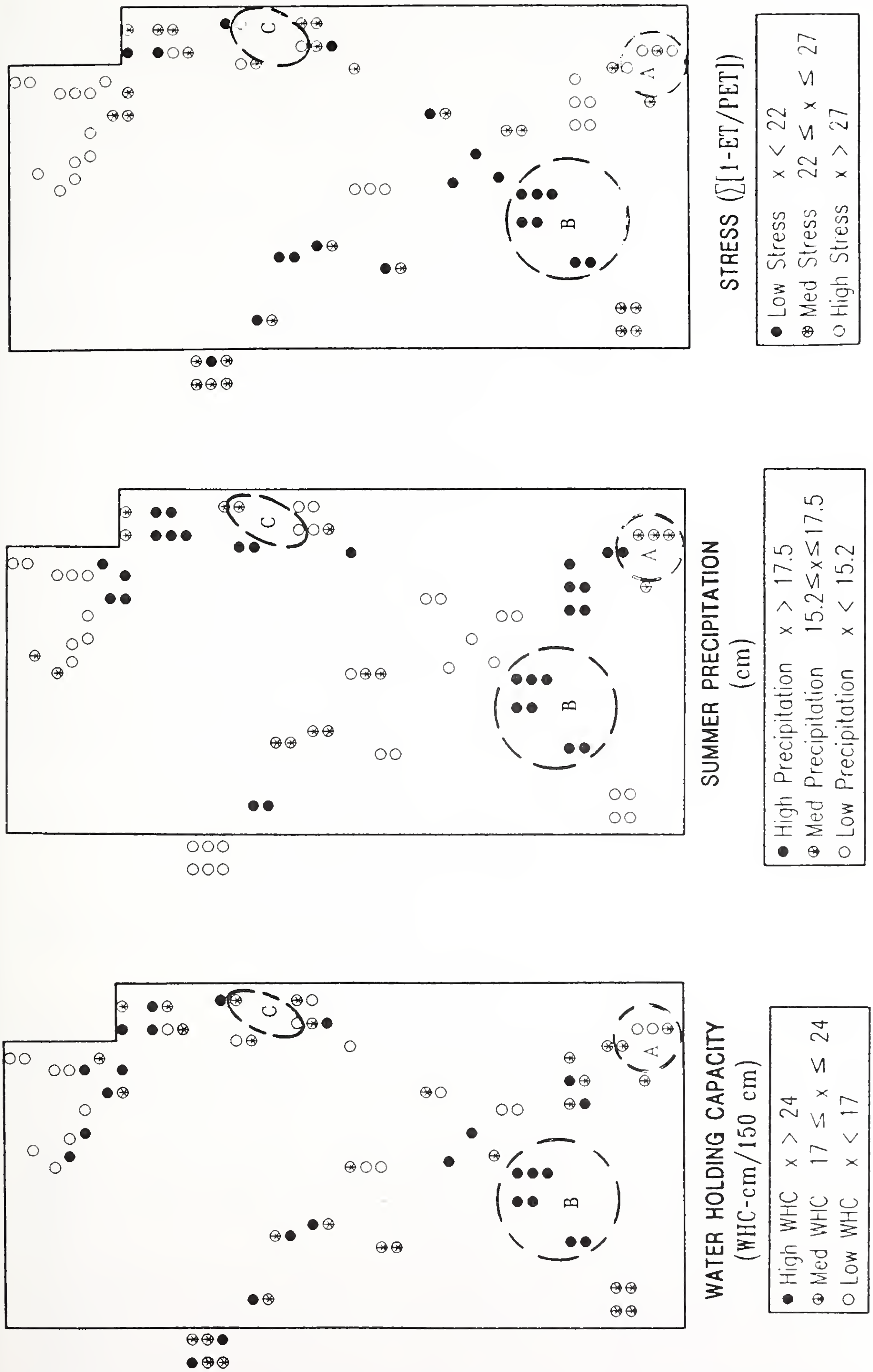

FIGURE 1. Spatial representation of soil water holding capacity, summer precipitation, and estimated moisture stress by plot, Wabash County - 1983.

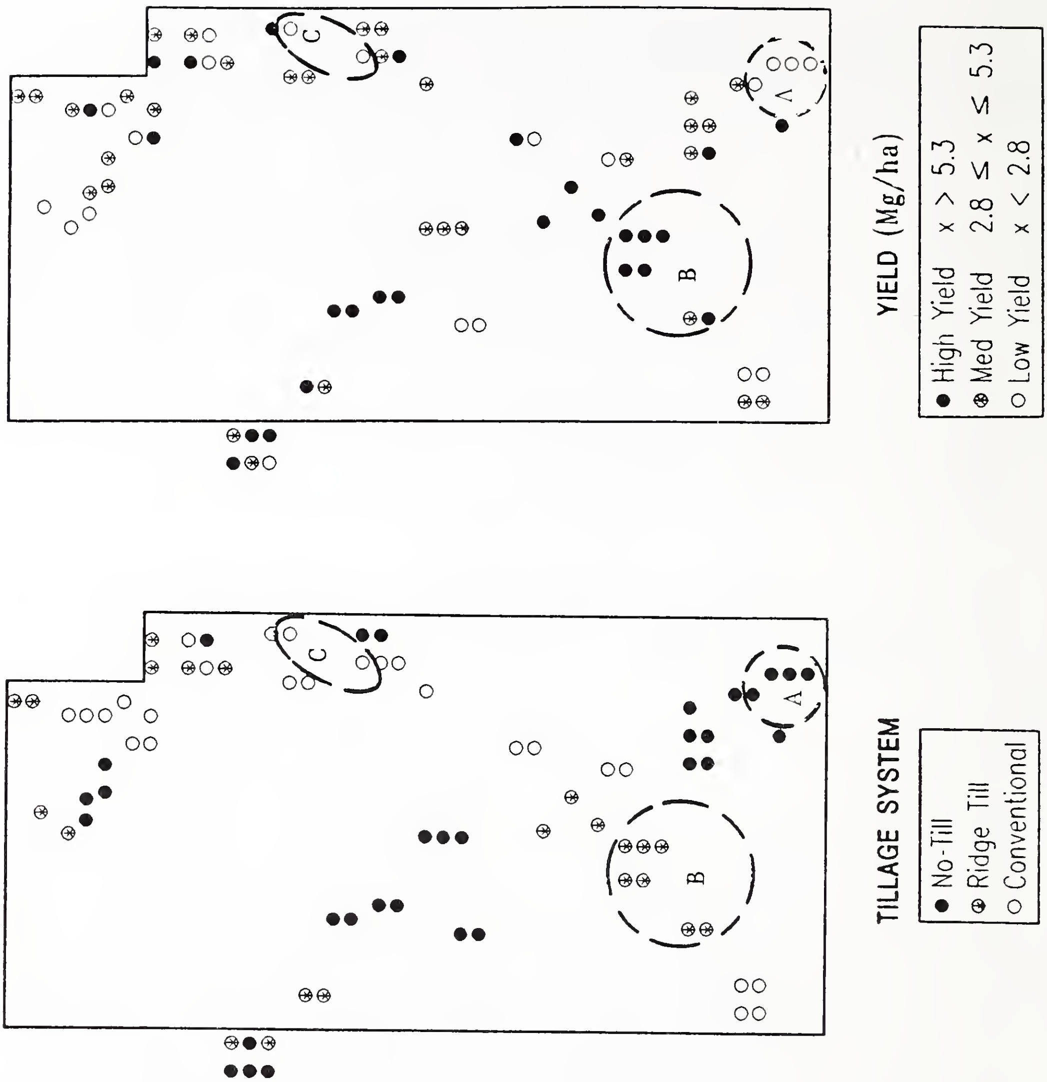

FIGURE 2. Spatial representation of tillage system and corn yield by plot, Wabash County - 1983.

used to estimate final corn yields (Y) were: both linear and quadratic terms for stress (S), nitrogen (N), and phosphorous (P); a binary variable for previous crop (PC); binary variables for the no-till (NT) and ridge-till (RT) systems; and no-till*stress (NT*S) and ridge till*stress (RT*S) interaction terms. Tillage system*stress interaction terms were included to consider differing corn yield responses to estimated moisture stress by tillage system. A N*S interaction as well as the weediness rating were both considered in early analyses, but the significance of each was low. Therefore, neither term is considered in the analysis presented.

Although the no-till and ridge till systems may conserve soil moisture more than conventional tillage (5), we should recognize that the development of the soil moisture model and resulting SIMBAL-generated ET/PET calculations are based on experimental findings on conventionally tilled soils. Thus, the interaction terms reflect only the yield effect stemming from the joint occurrence of the tillage system used with the calculated moisture stress based on the respective WHC and weather data.

Results

The regression coefficients for the model considered,

$$Y = b_0 + b_1S + b_2S^2 + b_3P + b_4P^2 + b_5N + b_6N^2 + b_7PC + b_8NT + b_9NT*S + b_{10}RT + b_{11}RT*S, \quad [1]$$

are shown in table 2 with variables defined. All but the intercept, the ridge till binary,

TABLE 2. Fitted regression coefficients for corn yield (Mg/ha) response [1] estimated from data obtained from Wabash County, Indiana farmers, 1983.

Variable	Coefficient#
Intercept	7.16
	(1.21)
S, Stress	-1.60*
	(-6.28)
S^2	0.0215**
	(5.15)
P, Phosphorous (kg/ha)	0.0314**
	(2.63)
P^2	-0.000105**
	(-2.81)
N, Nitrogen (kg/ha)	0.22**
	(3.80)
N^2	-0.000556**
	(-3.78)
PC, Previous crop (O = corn, 1 = soybeans)	1.47**
	(3.21)
NT, No-till binary (NT = 1; RT, Conv = 0)	-5.34*
	(-1.84)
NT*S, No-till*stress (interaction)	0.21*
	(1.99)
RT, Ridge-till binary (RT = 1; NT, Conv = 0)	-3.36
	(-1.25)
RT*S, Ridge-till*stress (interaction)	0.11
	(1.08)

R-square - 0.66, Adj. R-square - 0.60
t values in parenthesis
** significant at one percent level
* significant at ten percent level

and the RT*S interaction variables are significant. The no-till binary and the NT*S interaction are significant at the ten percent level; the rest are significant at the one percent level. The F value for the regression (11.4 for 11 and 66 d.f.) was highly significant although the adjusted R^2 was only 0.60.

In 1983, moisture stress had much greater effect on corn yields than did nitrogen *within the 100-200 kg/ha* range used by the farmers. The phosphorous results also indicate a flat relationship. That is, although the coefficients were significant, corn yield was affected very little as the N and P levels changed within the fairly optimum range used by the farmers.

The regression results indicate that corn planted after soybeans yielded 1.47 Mg/ha (23.5 bu/ac) more than corn after corn, a higher estimate than is normally suggested, especially since some of the legume effect is included in the N variable. Some agronomists hypothesize that the allelopathic effect is larger in dry years, thus this estimate is possible given the extreme conditions of 1983 (8).

In the range of the stress variable reflected by the 1983 observations, as stress increased, corn yield decreased at a decreasing rate. Relationships between stress and yield are plotted in figure 3 for the three tillage systems evaluated for corn following

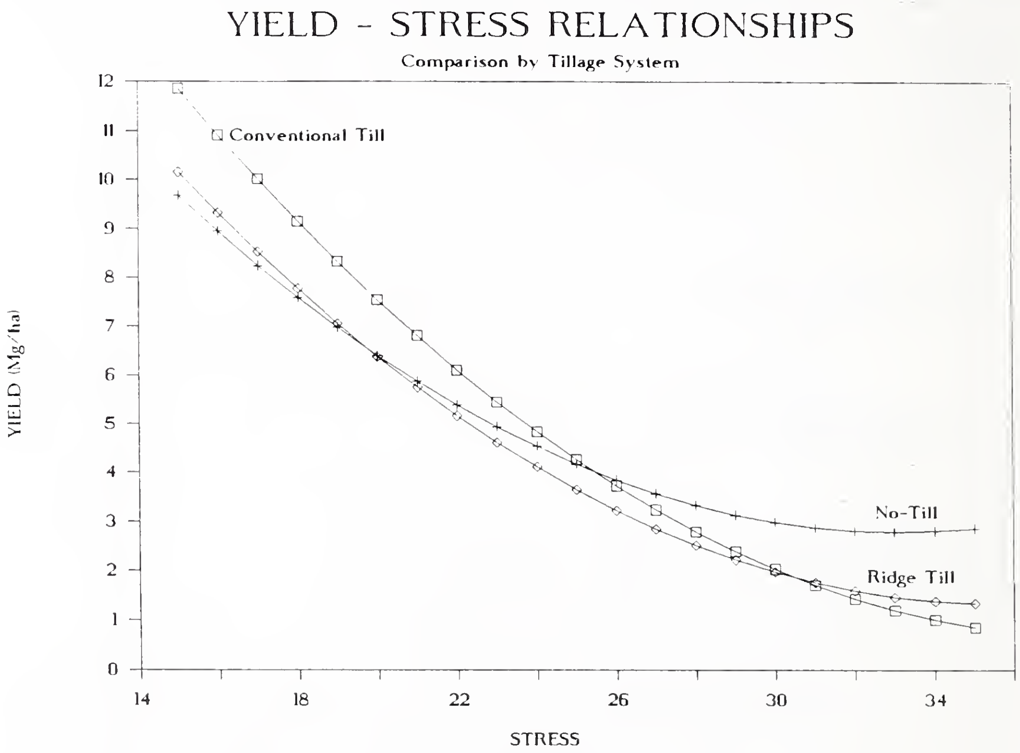

FIGURE 3. Regression model ([1], table 2) of corn yield on stress for indicated tillage system for corn following corn at average fertility levels (N = 200 kg/ha, P = 140 kg/ha). Wabash County - 1983.

corn (PC=O) and the average fertility levels observed on the plots in the study, approximately 200 kg/ha of applied nitrogen and a phosphorous level of 140 kg/ha.

None of the tillage system coefficients were significant at the one percent level of confidence, but the no-till and NT*S coefficients are significant at the 10 percent level of confidence. The three fitted curves in figure 3 show dramatic yield decreases with increasing stress compared to the differences between tillage systems. At the mean level of stress in 1983 (26), the no-till system yielded only 0.1 Mg/ha less than the conventional systems. But as stress increased, the no-till system became more attractive relative to the conventional system. In fact, if moisture stress were greater than 27, estimated no-till yields are greater than those on conventional plots. With little stress, however, conventional yields were higher. Such results suggest the effect of the tillage*stress interactions, although we should caution that the 95% confidence limits on the mean yield predicted for each of the three tillage systems in figure 3 overlap.

Concluding Comments

The hypothesis, suggested by the initial averages, that ridge till corn yields were significantly higher than corn yields under the conventional system cannot be accepted using 1983 Wabash County data. We conclude that no significant differences in *mean* corn yields due to tillage system remain after adjustments are made for differing levels of other inputs. The most important input in explaining the initial difference in corn yields was moisture stress. The results do suggest, however, that corn yields under both the no-till and ridge till systems improve relative to conventional tillage as the moisture stress experienced by the corn plant increases. The results lend some support to the hypothesis that no-till has some yield advantage over both the ridge and conventional tillage systems in extremely droughty conditions.

Note, however, that the tillage coefficients are not as highly significant as others in the regression and that the study only reflects results from a single year characterized by considerable spatial weather variability within a single county. While we believe the results are in the proper direction, additional research is necessary to better understand the complex relationships among plant growth and final yield with climatic factors, soil properties, fertility, and tillage system.

Acknowledgments

This research was supported by Indiana Agricultural Experiment Station Research Project 45099; the Department of Agricultural Economics, Purdue University; and the National Fertilizer Development Center, Tennessee Valley Authority under contract TV-18944A to Purdue University.

The cooperation of the Wabash County farmers who worked with us on this study is appreciated. We also wish to thank Vince Harrell, the Wabash County Cooperative Extension Agent; Mel Boyer, former SCS District Conservationist; Don Ruesch, SCS Area Soil Scientist; and Ray Sinclair, SCS State Soil Scientist. Their patience and interest in this project are much appreciated. We also appreciate the cooperation of other scientists at Purdue University. Bill Moldenhauer (ARS/USDA-retired); Don Griffith, Jerry Mannering, and Dave Mengel (Dept. of Agronomy); and Sam Parsons (Dept. of Ag. Engineering); all provided valuable input into this research. We also appreciated Jerry Mannering's review of an earlier version of this paper.

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APPENDIX. Individual plot data for variables used in regression model [1] or plotted in figures 1 and 2. Wabash County study—1983.

Yield Mg/ha	Stress	Water Holding Capacity cm/150cm	Summer Precip cm	Tillage# System	Previous& Crop	Applied* Nitrogen kg/ha	Soil Phosphorus kg/ha
3.06	25.3	16.2	14.4	C	C	169.1	104.2
2.51	26.0	16.5	14.4	C	C	169.1	65.0
7.22	15.7	25.3	18.0	R	C	213.9	152.3
9.64	15.8	24.7	18.0	R	C	213.9	98.6
4.08	23.6	20.7	12.8	R	S	208.3	107.5
3.75	29.6	15.8	20.7	C	S	189.3	32.5
6.68	20.7	23.2	13.3	N	S	253.1	185.9
6.79	22.3	25.3	12.8	R	S	208.3	96.3
4.43	26.7	17.2	20.7	C	S	189.3	23.5
5.96	24.4	25.3	12.8	N	S	230.7	197.1
4.34	26.7	20.7	12.8	N	S	230.7	140.0
7.52	22.6	25.3	17.8	R	S	228.5	224.0
4.55	23.3	20.6	17.8	R	S	228.5	82.9
1.88	24.7	25.6	13.3	N	S	253.1	161.3
5.64	21.8	25.6	18.3	R	C	189.3	174.7
3.79	23.4	25.6	18.3	C	C	142.2	156.8
4.50	24.5	20.1	18.3	N	C	142.2	65.0
1.04	30.2	15.8	18.3	C	C	189.3	109.8
3.22	26.1	18.0	18.3	R	C	189.3	129.9
4.69	24.3	18.0	14.2	N	S	161.3	44.8
3.48	23.4	16.5	14.2	N	S	161.3	49.3
2.13	27.6	14.8	14.2	C	C	142.2	96.3
4.58	25.8	18.0	14.2	C	C	142.2	113.1
6.00	21.1	26.5	17.1	C	C	142.2	107.5
3.46	23.5	16.5	19.1	C	C	157.9	268.8
3.30	34.9	12.8	13.7	N	S	188.2	268.8
3.21	30.8	24.4	12.8	N	S	188.2	268.8
3.48	44.5	16.0	13.8	R	S	219.5	268.8
1.61	33.9	9.8	17.0	R	S	237.4	116.5
3.86	40.6	9.4	13.8	R	S	219.5	88.5
5.03	34.9	13.9	13.7	N	S	188.2	268.8
0.98	30.5	25.8	12.8	N	S	188.2	268.8
3.14	35.5	11.7	13.8	C	S	201.6	156.8
2.09	31.0	11.3	13.8	C	S	201.6	268.8
5.51	28.6	29.9	13.8	C	S	201.6	155.7
1.60	32.5	10.7	17.0	R	S	237.4	191.5
4.29	26.8	19.1	15.7	R	S	213.9	50.4
8.46	22.2	25.6	15.7	R	S	213.9	60.5
4.08	25.6	25.5	18.5	C	C	190.4	174.7
7.71	21.2	25.3	16.6	N	S	216.2	203.8
6.98	20.8	27.6	16.8	C	S	164.6	268.8
1.89	27.7	18.0	16.8	C	S	164.6	257.6
8.63	21.2	25.3	17.3	N	S	216.2	197.1
6.96	21.6	22.3	16.6	N	S	216.2	73.9
4.66	37.3	17.8	13.5	N	C	246.4	129.9
2.93	28.4	20.4	18.5	C	C	190.4	216.2
6.99	24.4	20.9	17.3	N	S	216.2	107.5
0.71	25.2	25.5	18.5	C	C	190.4	268.8
5.51	26.4	20.7	18.5	C	C	190.4	144.5
4.65	40.0	16.3	17.2	N	C	179.2	90.7
3.11	39.7	16.8	17.2	N	C	179.2	104.2
8.56	21.7	18.0	13.1	C	S	244.2	60.5
1.57	23.7	16.0	13.1	C	S	244.2	52.6
4.80	33.1	18.0	18.5	N	S	183.7	136.6
6.13	29.2	25.6	18.5	N	S	183.7	129.9

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Appendix. Individual plot data for variables used in regression model [1] or plotted in figures 1 and 2. Wabash County study—1983.

Yield Mg/ha	Stress	Water Holding Capacity cm/150cm	Summer Precip cm	Tillage# System	Previous& Crop	Applied* Nitrogen kg/ha	Soil Phosphorus kg/ha
4.08	29.3	25.6	18.5	N	C	161.3	133.3
3.44	33.4	19.1	18.5	N	C	161.3	248.6
3.04	36.0	17.5	18.5	N	S	183.7	52.6
6.48	15.3	25.0	13.4	R	S	274.4	73.9
9.10	17.4	25.0	18.0	R	S	250.9	268.8
7.36	17.9	26.5	18.0	R	S	250.9	57.1
7.00	16.2	29.9	18.0	R	S	250.9	248.6
6.49	17.2	22.3	14.5	R	C	168.0	104.2
10.05	15.9	27.7	14.5	R	C	168.0	107.5
4.61	23.7	20.1	20.9	N	C	198.2	78.4
1.89	27.5	18.6	20.9	N	C	198.2	54.9
1.43	30.9	15.8	17.0	N	S	145.6	209.4
2.06	25.8	15.4	17.0	N	S	145.6	109.8
2.49	27.4	18.0	17.0	N	S	145.6	57.1
5.73	23.7	19.2	17.0	N	S	146.6	69.4
1.88	22.1	20.6	13.5	N	C	136.6	129.9
2.08	23.2	19.2	13.5	N	C	136.6	268.8
5.09	20.4	26.4	18.5	R	S	246.4	90.7
7.47	20.4	27.7	18.5	R	S	246.4	71.7
3.55	26.5	21.9	14.2	C	C	172.5	44.8
4.73	23.7	21.9	14.2	C	C	172.5	107.5
1.86	25.9	20.9	14.2	C	C	172.5	59.4
0.46	24.5	18.6	14.2	C	C	172.5	47.0

C - conventional tillage, R—ridge till, N—no-till

& C - corn, S - soybeans

* Nitrogen applied; plot application increased by 22.4 kg/ha for corn in rotation with soybeans to account for nitrogen fixation of the legume crop.