The effects of erosion control practices, management, weather and soil properties on corn yields on soils of southwestern Iowa

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INTRODUCTION

In many areas of the United States, soil erosion has become a serious agricultural problem and the State of Iowa is no exception. People attribute this to several causes but increased production of row crops is the principal cause. For example, Moldenhauer and Amemiya (1969) estimated that in the deep loess soils of western Iowa, a corn-corn-soybean rotation without erosion control can result in soil losses as great as 42 tons per acre annually from 9% slopes 300 feet long, or 27 tons annually from 6% slopes 400 feet long. This means that in only 20 to 30 years six inches of the top soil can be lost from soils that have an allowable loss of only 0.03 inch annually.

With millions of acres of land susceptible to water and wind erosion, methods to overcome these losses are very vital. Therefore, much research has gone into solving this problem but much of this has been devoted to studying the measures that affect run-off with its subsequent nutrient and soil losses. These measures include level terracing, contour surface planting, contour listing, and more recently, mulch tillage methods. Unfortunately, not much has been done to relate erosion control measures to crop yields.

It must also be strongly emphasized that complex interrelationships among factors and interactions of factors determine crop yields. Any yield prediction model which does not incorporate factors other than the one being studied is inadequate and incomplete.

Though erosion control is possible through the manipulation of land cover, slope length, and degree of slope, the effects of these factors on soil losses depend on other controlled and uncontrolled factors such as management, environment, weather, and soil properties. In most of the erosion control studies, however, these other yield-influencing factors were either held constant or disregarded.

To study the interrelationships among erosion control and other variables on corn yields, data were collected from three soil association areas in southwestern and western Iowa. These data were collected as a part of the statewide Corn Yield Study project of Dr. L. C. Dumenil. These areas were chosen because soil erosion has been a problem and, consequently, more erosion control practices have been used here than in other parts of Iowa. Only the data from the upland soils were included in this study. Data on corn yields and other variables influencing corn yields were analyzed by multiple curvilinear regression techniques to select the most important terms for inclusion in the yield prediction equations.

The major objectives of the study presented in this report therefore were:

1. To determine the effect that conservation practices have on corn yields,

2. To build a yield model in which the most important soil erosion control, management, environment, weather, and soil variables were included, and
3. To study the most important interactions among these variables on corn yields.

LITERATURE REVIEW

Erosion and Its Effects

The study of the detrimental effects of erosion merits special attention in western Iowa. In this area, most of the soils are formed in deep loess and the subsoil textures vary from silt loam to heavy silty clay loam. Several researchers (Aandahl, 1949; Engelstad, 1960; Peperzak, 1956) have indicated that the effect of surface soil removal on crop yields is largely a fertility effect in the deep, medium-textured soils which have little increase in the clay contents in the subsoil.

Mattyasovsky and Duck (1954) attributed the detrimental effects of erosion to these causes: (1) direct loss of nutrients, (2) loss of surface runoff, (3) reduction of the thickness of the profile, (4) deterioration of the physical properties of the remaining soil, and (5) deterioration of its water economy.

Effect of Water Erosion on Direct Loss of Nutrients

The depletion of the soil of nutrients through erosion has been extensively studied. Slater and Carleton (1938) found a correlation between the decrease in organic matter content and soil loss at erosion experiment stations at Bethany, Missouri, and Clarinda, Iowa. A 0.002% drop in organic matter content was observed for each ton of soil lost through erosion.

Kohnke (1941) established that runoff water with its associated material is high in solid soil particles, especially clay and organic matter, high in total N, high in absorbed P, but is low in soluble salts.

Neal (1944) working on Collinton sandy loam found similar results. He observed that the average content of particles less than 50 microns in diameter in the surface of the original soil was 16% but the eroded material contained 58%. In comparison with the original surface soil, the eroded material contained 4.7 times as much organic matter, 5.0 times as much N, 3.1 times as much P, and 1.4 times as much K. His chemical studies indicated that the availability of P in the eroded material was equal to that in the soil but the available K was 3.7 times higher in the eroded material than in the original soil. Erosion losses of N in comparison with crop removal were comparatively small in all cases.

Stoltenberg and White (1953) found erosion to be a selective process such that the eroded material contained considerably more plant nutrients than the soil from which it was eroded. The N and P contents of the eroded material were almost double the amounts in the surface soil, while the K content of the eroded material was seven times that of the soil.

In Wisconsin, Massey and Jackson (1952) found that the percentage content of N in the eroded material averaged 2.7 times greater than the percentage content of N in the original soil.

According to Black (1968), as a result of concentration of total and mineralizable N in the upper part of the soil profile, loss of surface soil by erosion significantly decreases the availability of N to plants and the N cannot be replenished by supplies in the subsoil.

Unlike N, the effects of losses of P by erosion vary with the type of soil. The loss of P from the surface soil is less serious if the subsoil has a high level of available P such as occurs in a Fayette silt loam as observed by Black (1968, p. 564-565). However, in Lindley silt loam only the upper A horizon had an adequate P supply and all other horizons were deficient in P. Black (1968, p. 660) also reported a considerable loss of K through erosion. However, losses of K are seldom taken as seriously as those of N because most soils have higher amounts of available K than N in their subsoils.

Reduction of the Thickness of the Soil Profile

One serious effect of erosion is the removal of the topsoil or A horizon. Stephenson and Thomas (1943) estimated that a yield reduction of 0.9 bushel per acre occurred for each inch of top soil removed through erosion. On a Shelby loam in Missouri, Smith et al. (1948) observed a yield loss of 4.0 bushels per acre for each inch of topsoil removed by erosion. Simonson and Englehorn (1939), who sampled corn yields of different soil types in Iowa, attributed the very wide differences in corn yields within the same field to differences in depths of the A horizons. Aandahl (1949) also found that higher yields were associated with thicker A horizons.

Two studies conducted by Engelstad et al. (1961) and Engelstad and Shrader (1961) investigated the effect of surface soil thickness on yields of corn to learn whether nitrogen fertilizer could substitute for surface thickness. In the first study on soils in the Marshall-Monona transition zone, they found through multiple regression analysis that loss of surface soil caused a reduction in corn yields. However, application of N fertilizer at the rate of 100 pounds per acre completely substituted for losses of surface soil in 1957 but not in 1958. The second study was on a Marshall silt loam from which the A horizon was removed prior to the start of the experiment. They obtained the same results as from the first experiment and they further established through regression analysis that the production of maximum corn yields on subsoil required more N per acre.

Effect of Erosion on Soil Parameters

Water erosion is perhaps the most spectacular of the erosion processes. This is because the concentrated water causes gullies in the landscape. Baver (1950) and Shrader et al. (1963) divided soils into two general groups related to the way in which crop production is affected by erosion. They classified in the first group the soils in which texture, permeability, ease of tillage, and other characteristics of the subsoil are similar to the properties of the surface soil. Cost of production on these soils at any given level of yield is increased by erosion but removal of the topsoil causes little or no reduction in maximum potential production. The Marshall silt loam and most of the other loess-derived soils of southwestern Iowa fall in this category.

The second group includes those soils in which the subsoil furnishes a distinctly inferior media for plant growth as compared to the surface soil. Erosion on these soils results in increased costs of production and, regardless of the practices used, yields on their subsoils are less than those obtained on their surface soils. On these soils, erosion results in a permanent disinvestment.

In whatever group a particular soil falls, soil erosion has adverse effects on it through the loss of nutrients and the changing of several properties of the soil. Slater and Carleton (1938) investigated the extent to which erosion has been a factor in reducing the organic matter content of plots on the erosion experiment stations at Bethany, Missouri, and Clarinda, Iowa. They found the depletion of organic matter to be a linear function of erosion and found determinable amounts of depletion occurring at the higher erosion rates.

Stoltenberg and White (1953) claimed that under the prevailing farming system, the loss by erosion amounts to about 0.3% of the organic matter per year. Due to the usual decrease in organic matter content with depth, the effects of the loss of organic matter through erosion is accentuated by plowing which brings the material lower in organic matter to the surface.

Nitrogen is also lost through erosion. Most of the N in the soil is in the organic matter and, therefore, any losses of the latter through soil erosion invariably lead to the depletion of the former.

Fixation of P by soil particles has often been given as the reason for the low accumulation of P in the surface soils. However, large amounts of P have been lost from cultivated fields through erosion. Scarseth and Chandler (1938), Rogers (1941), and Ensminger (1952) studied the loss of applied P through erosion. Most of their work showed that slight amounts of phosphates moved into lower layers of the soil and, obviously, the greater part remained in the upper portion. Therefore, much of the P is lost and accumulation is hindered in those areas where erosion is great throughout the year. Rogers (1941) found that the more readily soluble forms of P and K were more concentrated in the eroded material than the less readily soluble forms. Ensminger (1952) reported similar results in Alabama.

In studying the distribution of P in some southwest Iowa soil profiles, Birchett (1974) found that very little chemically extractable P was present between 12 and 48 inches in depth in the Ida soils. In the Monona, Marshall, and Sharpsburg profiles, low to medium amounts of extractable P were found at the 36-48 inch depths. Except for the Ida soils and some of the Monona soils, the loss of the A horizon from the southwestern Iowa soils will not lead to a severe deficiency of P.

Erosion can also damage the soil through modification of some important physical parameters. Bennett (1939) reported that erosion increases the coarseness of the soil of the surface by removing fine material. Cultural practices counteract this effect by mixing subsoil which is usually heavier in texture than the remaining surface soil so that as erosion proceeds, the texture of the cultivated zone gradually approaches that of the underlying subsoil.

Lal (1976) studied the effect of soil erosion on the physical properties of Alfisols and their crop responses in western Nigeria. He observed that soil erosion increased the gravel content and decreased the silt and clay contents of the surface horizon. The moisture retention capacity of the surface decreased significantly. The infiltration rate also decreased. Ellison (1947), studying the effect of erosion on soil structure, reported that the splashing raindrops broke down clods and aggregates releasing humus and clay materials. This was accompanied by puddling and compaction and colloids were carried down into the profile. These colloids tend to consolidate profile materials, give it strength and firmness, and decrease its permeability.

Erosion Control

Soil erosion control is defined by Blase and Timmons (1961) as

> The prevention of the diminution of the discounted value of future production from a given area of soil, a given level of expected production technology, a given discounted value of labor and capital, exclusive of the value of the soil-erosion-control input.

The methods for reducing erosion may be grouped into two broad categories:

1. <u>Land treatment practices</u>. These are primarily agronomic in nature and include use of various forms of vegetation as cover, tillage, planting, cultivation practices, terracing, contouring, and ridge farming. These practices

   > Incorporate many of the same principles of water-flow control to reduce or eliminate sheet erosion, that is, the interception of precipitation near the arrival site, surface detention, silt deposition, water infiltration, slow release of excess water, and degradation

> or attenuation of potential pollutants within the biologically and chemically active soil filter (Willrich, 1967, p. 305).

2. Engineering structures. Their primary function is to control the rate of water flow both over the land and in the streams. This category includes small grade stabilization structures, larger gully stabilization structures with water detention features, desilting basins, and larger reservoirs. Additional engineering practices would include the commonly used flocculation and rapid sand filtration techniques employed in municipal water treatment plants (Linsley and Franzini, 1964) as well as the still experimental use of polynuric flocculants for in-place river water clarification (Katzer and Pollack, 1968).

All practices or structures for erosion control are designed to do one or more of the following: (1) dissipate raindrop impact forces, (2) reduce quantity of runoff, (3) reduce runoff velocity, and (4) manipulate soils to enhance their resistance to erosion. In this study the major concern was to investigate the effect of the land treatments and their effects on corn yields.

Contouring

This is the field practice in which rows are oriented on the contour, generally with a slight grade toward a waterway.

The resistance to flow and the surface storage thus provided slow down the runoff and give the water more time to infiltrate into the soil instead of directly running off. Contour planting functions to control runoff and soil loss from storms that are moderate in extent, or until the capacity of soil to hold or to prevent runoff is exceeded (Amemiya, 1970). On uncontoured land the same rain would cause runoff much sooner and the soil particles contained in the water would fill up the pores of the soil surface thus sealing it and lowering the infiltration capacity. This results in still greater rates of runoff (Kohnke and Bertrand, 1959, p. 177).

It is evident that contouring results in accumulation of soil moisture. This is an advantage on permeable soils on pronounced slopes (Schaller and Willrich, 1962). Several workers in various parts of the United States have shown that contour farming saves from 0.5 to 9.0 inches of water per year and from 0.3 to 41.8 tons of soil per acre. Smith and Wischmeier (1962) found that on slopes of moderate steepness and length, average annual soil loss can be reduced by about 50%. Kohnke and Bertrand (1959, p. 182) reported a 10% yield increase from contouring due to moisture conservation and protection of the seedling plants from washing out; it also decreased the power requirement for tillage about the same percentage.

Jamison et al. (1968) studied the effect of contouring on runoff and soil loss from continuous corn at McCredie, Missouri, on plots with 2-4% slope and a length of 420 feet. For the 1959-1961 period, runoff was 3.9 inches from the non-contoured plots and 1.7 inches from contoured plots and soil losses were 8.6 and 6.2 tons per acre, respectively. They concluded that although growing corn on the contour may conserve water and save soil during most seasons, the hazard from high-intensity storms that sometimes occur during the critical period for corn production may be increased by the practice.

Schaller and Willrich (1962) referred to a 5-year study on 260 Iowa farms which showed that yields were increased from contour farming. A corn yield increase of 7.3 bushels per acre was observed because the stands were better and more water was available for plant use. In the same test, contouring increased oat yields by 5.0 bushels and soybean yields by 2.5 bushels per acre.

Moldenhauer and Wischmeier (1960) reported the effects of erosion control practices on soil and water losses in western Iowa (Table 1). Savings of soil and water occurred from contouring and from contour listing although the lister ridge was eliminated by the second cultivation.

Although contouring has the advantages discussed previously, this practice has its limitations. Contouring introduces point rows which are difficult to farm. There is also the hazard of possible accumulation of water in danger spots of the slope if the lines are off the contour causing

Table 1. Effects of erosion control practices on soil and water losses, Ida silt loam, 1948-1957

Practices	Soil loss (tons/acre/year)	Water loss (inches/year)
Corn-oats (sweet clover catch)		
Up and down slope	25.2	3.23
Contouring	10.1	2.08
Contour listing	4.9	1.4
Corn-oats-meadow-meadow		
Contour listing	1.3	0.57

a mass break when a heavy rain occurs. However, adjustment of the tillage direction and establishment of sod waterways are the remedies.

Terracing

Terracing is one of the oldest practices used to control erosion. Terraces are combinations of ridges and channels laid out across the slope to trap water running downslope and to conduct the water to suitable surface or subsurface outlets at a nonerosive velocity. The primary benefit of terracing is the reduction in slope length (Amemiya, 1970). Since erosion is approximately proportional to the square root of slope length, reducing slope length by half can reduce erosion by more than 20%.

In the United States, terracing appears to be the most widespread erosion-control practice and the broad-based Mangum terrace is the one which is most commonly used because this concentrates runoff in less than 10% of the field area. Although they are effective for erosion control, they are not compatible with efficient tillage operations or modern farm equipment. In addition, herbicides are making it increasingly difficult to maintain grassed waterways. To overcome these problems, Zingg and Hauser (1959) and others, introduced the broad channel-type terrace. Most tests on the broad-channel terraces show that in order to obtain the highest yields, the entire farmed area has to be leveled which can be very costly (Wittmuss et al., 1968).

A recent improvement in terrace design has been a system of bench terraces known as "push-up" terraces with permanently vegetated backslopes. In this system, all runoff is collected in low spots in the terrace channel and, if necessary, removed through underground tile outlets to grassed waterways. Terraces can be constructed parallel and alignment materially straightened, thereby eliminating objectionable point rows. In time, sediment deposited in the channel reduces the slope in terrace intervals (Jacobson, 1969).

Jamison et al. (1968) claimed that this switch from the conventional to parallel terraces nearly doubled the average contour row length, reduced the number of turns, and decreased point row area by 70%. Average rate of travel of farm equipment was 16% faster on land with parallel terraces and the average time saving in production of corn and soybeans was about 24%.

Although terracing has been found to increase crop yields, some workers have observed that under some conditions corn yields may be lower on terraced than unterraced fields. This is illustrated in Table 2 by the unpublished data from Dr. W. D. Shrader, Agronomy Department, Iowa State University. Lower yields of terraced fields were attributed primarily to differences in fertility, loss of land area in terraced backslopes, and poor drainage in wet years in terrace channels. Miller (1970) also observed a differential moisture condition at different positions on terraced land. He found that moisture differences favored corn yields in terrace channels in the drier years over the terrace intervals, but in wet years, terrace intervals had more favorable moisture relationships.

Some disadvantages associated with terracing have been the principal hindrance to its adoption in western Iowa. A possible accumulation of water in the low spots of the channels can spill over the ridges, wash them out, and cause severe gullying. Due to the extensive earth movement, infertile subsoil is frequently exposed at the surface. This can cause low crop yields during the first few years of the practice. The sod strips on the backslopes can harbor a variety of insect and rodent pests, including gophers and groundhogs which can damage the terraces causing periodic

Table 2. Average yields from terraced and unterraced (contoured) fields, Treynor, Iowa[a]

	Corn yields (bu/acre)	
Year	Terraced	Contoured
1970	93	102
1969	115	120
1968	92	103
1967	78	104
1966	79	84
1965	53	78
1964	56	72
Average	81	95

[a] W. D. Shrader, Department of Agronomy, Iowa State University, Ames, Iowa. Cooperative studies on soil moisture and crop production at Treynor, Iowa. Mimeo. 1970.

failure during high rainfall periods.

However, according to Amemiya (1970), terracing is generally considered a more effective erosion control measure than strip cropping, the only disadvantage being the high costs of terracing. Terracing supports contouring by acting as a safety measure to prevent serious field gullies when contour rows break. The combination generally confines the soil losses within field boundary.

Vegetative cover

Several researchers, including Moldenhauer and Wischmeier (1960) and Schmidt (1961), have established that erosion can be controlled by a vegetative cover on very adverse sites and this offers the greatest possibilities for erosion control in humid regions. The tall grass prairie community of vegetation, for example, was an almost ideal cover from an erosion standpoint, but all of the prairie has been destroyed. We will not likely restore large areas to prairie vegetation, but we can move in that direction by utilizing cropping systems that keep the land under a vegetative cover during a large portion of the year.

An extensive survey by Coleman (1953) led him to conclude that rotations that include one or more years of close-growing vegetation generally reduce surface runoff and erosion. He found also that hay or pasture was the most effective.

Residue mulches and minimum tillage

Residue mulches have been found to be one of the effective erosion control measures and reduce runoff by reducing surface sealing and crusting. Primarily, they reduce sediment concentration in the runoff by reducing the detachment capacities of both rainfall and runoff (Wischmeier, 1973).

Moldenhauer and Amemiya (1969) reported that soil losses from Wea silt loam in Indiana were reduced to zero with two tons of mulch applied to plowed soils. Bearle et al. (1955) performed an experiment on a moderately to severely eroded Cecil sandy loam in South Carolina and observed that mulching was very effective in reducing runoff during the growth of corn.

Of late, a number of minimum tillage systems has become an important tool for erosion control. Minimum tillage as defined by Wittmuss et al. (1973) is the minimum soil manipulation necessary for crop production or meeting tillage requirements under existing soil and climatic conditions. Minimum tillage does not define a system of tillage, but generally refers to a system with fewer tillage operations than conventional tillage. In the area under study, conventional moldboard plowing was the dominant primary tillage practice.

Effects of Management on Yield

Soil and crop management has improved markedly in present day agriculture and the selection of the optimum management variables must be done every year for each field. Exceptional management skills together with a sound technological background are required to grow top yields of corn, especially on eroded soils. Henao (1976) has reviewed extensively the general effect of management variables on yield. In this work, therefore, only the effect of management on eroded soils is discussed.

The importance of fertilizers in reclamation of eroded lands cannot be overemphasized. Nitrogen is a major plant nutrient and it is needed in large amounts for high yields of corn in intensive systems of agriculture (Kurtz and Smith, 1966). Englehorn et al. (1964) found that any reductions in corn yields were caused invariably by the depletion of soil N and organic matter. Phosphorus is also an important plant nutrient which has many vital roles in the physiological processes of the plant. The corn plant also requires large amounts of K for its growth. A 100-bushel corn crop may contain 120 pounds or more of K in the above-ground portion of the crop and about 25 pounds in the grain (Pierre et al., 1966).

Fertilizers are needed to replenish these important plant nutrients when they are eroded from the soil. The application of inorganic fertilizers in addition to manure increases yields on severely eroded soils. Browning et al. (1947) found that annual application of 8 and 16 tons per acre of barnyard manure and leguminous green manure materially reduced soil losses and increased crop yields on eroded Marshall soils which had lost 50% of their topsoil through erosion. Smith et al. (1945) reported similar results on Shelby soils at Bethany, Missouri, which were severely eroded and gullied with less than 40% of the surface soil remaining. They also applied 3 tons of lime per acre and 250 pounds per acre of 4-12-4 fertilizer. Less runoff, less soil loss, and higher yields were obtained on the treated than on the untreated soils. Whitaker et al. (1961) found that the application of adequate fertilizers increased yields four times on an eroded Mexico silt loam in Missouri. Moldenhauer et al. (1967) reported the results from the erosion research at

Clarinda, Iowa, from 1932 to 1962. They observed that before 1953, soil erosion rates were high on continuous corn plots. However, after annual applications of 179 kg of N per hectare yields were markedly increased and erosion losses from the continuous corn decreased.

Effects of Weather on Yield

Weather is an increasingly important factor in crop production. Farmers now have available technology to produce 125-150 bushels of corn on good soils with favorable weather. In this study, the weather variables included both the deficiency and excess of moisture. In the deep loess area of western Iowa, inadequate amounts of soil moisture during the growing season limit corn yields more often than any other single factor.

Although the soils of this area are deep and permeable with high plant-available water capacities, high rates of evaporation, erratic precipitation and soil erosion reduce soil water storage. In addition, surface runoff from sloping areas is a loss of potential soil moisture for use by corn (Miller and Shrader, 1976).

Several researchers including Hendericks and Scholl (1943), Thompson (1963), Dale and Shaw (1965), Corsi and Shaw (1971), and Shaw and Felch (1972) have developed moisture stress indexes based on the daily balance between soil moisture and atmospheric demand. These have been discussed by

Morris (1972) and Henao (1976). Many researchers have studied how to minimize or prevent moisture stress in order to obtain high crop yields.

Miller and Shrader (1976) developed a yield response curve applicable in western Iowa for a wide range of soil moisture stress conditions. They also evaluated the potential effect of a moisture conservation technique in terms of corn production. They observed that the potential for moisture conservation and increased yields due to reduced evaporation and surface runoff resulting from the use of conservation tillage is very high. Many other workers have found different tillage systems to be effective in moisture conservation. Moldenhauer et al. (1971) reported that tilled soil with a mulch cover maintained a higher infiltration rate than tilled soil with no mulch, and therefore had less moisture stress; both had higher infiltration rates than untilled soil with a mulch.

Terracing is one of the basic practices in a successful plan for conservation of soil and water on sloping land. It is not necessarily the complete solution to the problem of moisture stress but it provides a basis or foundation for the effective use of water by the plants. Beasley (1972) claimed that level terraces are effective in conservation of water and in the reduction of surface runoff, especially so in areas of limited rainfall and where rain comes in a few intense storms during the growing season. Crop rows planted across the slope with terraces will also impound runoff and provide additional time for water to infiltrate into he soil.

Morris (1972) reviewed the literature on the effects of excess moisture on soils and crop growth. He derived excess moisture indexes along with moisture stress indexes by using a simulated model for rainfall infiltration, moisture redistributions throughout the soil profile, and moisture balance in the soil depending on atmospheric and crop demand. Henao (1976) modified this excess moisture index and showed that excess moisture had a negative effect on corn yields.

MATERIALS AND METHODS

General Information

Corn yield and other data were collected under the supervision of Dr. Lloyd C. Dumenil of the Agronomy Department for the Iowa Agriculture and Home Economics Experiment Station Project 1377 (replaced by Project 1958 in 1972 and then Project 2326 in 1978). Cooperating in the field phases of this research were the Iowa Cooperative Extension Service, the Soil Conservation Service, USDA, and many farmer cooperators and volunteer rainfall observers. The title of the project was: Crop yielding capacity of Iowa soil types under different soil, management and fertility levels.

The primary objective of this project was to determine for the various soils of the state the crop yield level that is attainable under different soil, management, and weather conditions. They used the point-estimate sampling in which the corn yield was determined at randomly selected sites (one plot per site) in selected Iowa counties. All environmental, climatic, soil, and management variables that could affect the corn yield at that specific site were either measured or estimated. The field research was initiated in 1957 and terminated after the 1970 season. The 15 counties selected represented all major soil association areas in Iowa, except the Adair-Grundy-Haig area in southern Iowa.

For this study, only observations from the upland soils from five sounties in the southwestern and western part of the state were used. These counties were Adams, Cass, Crawford, Harrison, and Woodbury. This area of the state was chosen because soil erosion has been a problem and the consequent employment of erosion control practices has been more prevalent than in other areas.

Occurring in this area were these major soil series: Adair, Clarinda, Dow, Galva (a few sites in northern Woodbury County), Ida, Macksburg, Marshall, Monona, Nira, Sharpsburg, Shelby, and Exira (formerly mapping unit 99). Some general information about these soil series is given in Table 3. These soils occur in the Sharpsburg-Shelby-Macksburg, Marshall, Monona-Ida-Hamburg, and the Galva-Primghar-Sac soil association areas (Fenton et al., 1971).

The data listing sheets (descriptions, symbols, units, and coding for analyses) for all of the variables used in this study are given in Appendix Table A1. Most of these variables were used by Henao (1976) in his study of the soil variables for regressing Iowa corn yields on soil, management, and weather variables. The field techniques, laboratory methods, and other statistical methods used to estimate most of the variables were explicitly explained by Henao (1976). However, several variables were added to this study and some were modified, as will be explained in the following sections.

Table 3. General information about the major soil series used

Soil series	Slope[a]	Erosion class[a]	Parent material	Natural internal drainage
Adair	7-16	1-3	Paleosol	Moderately well to somewhat poor
Clarinda	4-8	0-2	Paleosol	Poor
Dow	11-15	1-2	Deoxidized, calcareous loess	Well
Galva	3-8	1-2	Loess	Well
Ida	5-20	2-3	Calcareous loess	Well
Macksburg	1-2	0	Loess	Somewhat poor
Marshall	1-13	0-2	Loess	Well to moderately well
Monona	1-20	0-3	Loess	Well
Nira	4-10	0-2	Deoxidized loess	Moderately well
Sharpsburg	1-12	0-2	Loess	Moderately well
Shelby	9-18	1-3	Glacial till	Well to moderately well
Exira	1-11	0-2	Loess, relict mottled	Moderately well

[a] Ranges of observations in this study.

Environmental and Weather Variables

The following environmental variables used in this study were the same as Henao (1976) used: time trend over years, percent barren stalks, total root lodging, corn root damage rating due to corn rootworm infestation, first and second brood corn borer infestations, total weeds, and silking date. Percentage of stalk lodging (breakage) below the ear was added to account for some of the yield loss from wind, 2,4-D, and stalk rot damage.

The excess moisture (EM3V) and moisture stress (DV) indexes and PPT75, the 75-day rainfall total from 42 days before silking to 33 days after 75% silking, were the same as used by Henao (1976). Two additional variables were added: the plant available water in the soil to a depth of five feet on April 15 (PAW) and the total rainfall from April 15 to 42 days before 75% silking (PPTEAR). The PAW, PPTEAR, and PPT75 were used to estimate the total water available in the current growing season. These variables were tested against the sophisticated weather indexes, EM3V and DV, to determine which group of variables could account for more yield variation.

Management Variables

The following management variables were the same as were used by Henao (1976): plant density (stand level), planting date, total N, P, and K from manure and fertilizer, and cropping sequence codes for N and K availability to the corn crop.

In the initial stages of statistical analyses, variables were added for manure rate in tons per acre and rates of N, P, and K fertilizers. The residual effects of N and P from manure and fertilizers were determined by the addition of the NRES1 variable (total N applied the previous year) and the PRES1, PRES2, and PRES3 variables (total P applied 1, 2, and 3 years prior to the year the corn yield was determined). A miscellaneous variable, coded row direction, was added to determine if it had any effect on yield.

Several tillage variables that might affect yields through their effects on erosion and water losses were added. These were fall vs spring plowing, moldboard plowing vs other seedbed preparation (although only 3% of the sites were not plowed in the 1958-1970 period), number of tillage operations after plowing and before planting, row width (although narrower rows were used only in the last few years), and the summation of times the field was harrowed after planting, rotary hoed, and cultivated.

Erosion Control Variables

Two of the erosion control variables were CPLOW and CPLANT which were dummy variables designated 0 = not contour plowed or planted and 1 = contour plowed or planted in the year the site was harvested. Terraced sites were listed as contour plowed and planted. Another variable was DTERR, the distance in feet to the top of the terrace above the site. This was coded 200 feet minus the distance to terrace; the coded distance was set equal to zero if the terrace distance exceeded 200 feet or if the field was not terraced. All of the terraced sites were located far enough below the backslope and above the channel to avoid any deposition or disturbance from the terrace building operation.

The cumulative effects of contouring and terracing over years on corn yields were initially tested by the YCPLOW, YCPLANT1, and YTERR variables. These were the number of years that the site had been contour plowed, contour planted, and terraced prior to and including the year the site was harvested. All sites not contour plowed, contour planted, or terraced (within 200 feet of the terrace) were designated zero.

Another variable related to erosion control was SLRATIO, the ratio of the slope of the rows to the slope of the site area (coded: ratio*100). Few noncontoured sites had rows up-and-down hill (SLRATIO = 100); the rows at the noncontoured sites varied from being on the contour to up-and-down hill. At some of the sites in contoured fields, the rows were off the contour with the SLRATIO being as high as 30 to 35.

Selections of the initial regression models were with various combinations of the six erosion control variables previously mentioned. These variables, as coded, did not give unconfounded comparisons of the contouring and terracing effects. Any of the contouring variables compared yields of the sites contoured only plus the terraced sites with those of the noncontoured sites. The terracing variables compared the yields of the terraced sites with those of the contoured plus noncontoured sites.

Two alternatives in the later stages of the model selection were used to obtain unconfounded estimates of the cumulative effects of contour planting and terracing on yields. First, the sites that were either contoured only or terraced were deleted alternatively and the regressions were run on the remaining observations. With the sites contoured only deleted, the yields of the terraced sites were compared with those of noncontoured sites. With the terraced sites deleted, yields of contoured sites were compared with those of the noncontoured sites.

The second alternative was to add another variable so that the unconfounded cumulative effects of contouring and terracing vs noncontouring could be estimated using all of the data. Since the YCPLANT1 and YTERR variables (cumulative effects over years of contour planting and terracing) had been selected as the best variables in the initial testing, a transformed YCPLANT2 variable was added. The YCPLANT2 value was set equal to YCPLANT1 value, but if YTERR was greater than 0, then the YCPLANT2 value was set equal to 0.

Effects on yield that the regression coefficients of each of the three variables estimated were as follows:

b_1*YCPLANT1 = effect of years terraced (A effect + effect of years contour planted (B effect) vs noncontoured (C effect). (1)

b_2*YCPLANT2 = effect of years contour planted (B effect) vs effect of years terraced (A effect) + noncontoured (C effect), and (2)

b_3*YTERR = effect of years terraced (A effect) vs effect of years contour planted (B effect) + noncontoured (C effect). (3)

From the above relationships in equations 1, 2, and 3, the unconfounded effects of years contour planted and years terraced can be obtained by adding the $b_1 + b_2$ and $b_1 + b_3$ regression coefficients, respectively, as follows:

Contour plant effect = $b_1 + b_2$ (4)

= A effect + (2) B effect vs A effect + (2) C effect

= (2) B effect vs (2) C effect

= B effect (contour planted) vs C effect (noncontoured), and

Terrace effect = $b_1 + b_3$ (5)

= (2) A effect + B effect vs B effect + (2) C effect

= (2) A effect vs (2) C effect

= A effect (terraced) vs C effect (noncontoured).

If squared and interaction variates are included in the regression model for each of the three variables (YCPLANT1, YCPLANT2, and YTERR), their regression coefficients are added along with their respective linear coefficients to get the unconfounded cumulative effects of contour planting and terracing as in equations 4 and 5.

Soil Variables

The following soil variables and their values were the same as those used by Henao (1976): soil pH, buffer pH, soil test N, soil test P, and soil test K of the plow layer; minimum pH in the subsoil and depth to the midpoint of the minimum pH; depth to the top of the calcareous (free carbonate) horizon; pH and soil test P level of the 30-42 inch layer; soil test K level of the 12-24 inch layer; slope, slope configuration, and aspect of the site; internal drainage and subsoil permeability classes; percent clay of the plow layer, maximum percent clay in the subsoil, and depth to the midpoint of the maximum clay horizon; bulk density of the 30-40 inch layer; biosequence; and depth to till and paleosol, depth to till in loess over till units, and depth to deoxidized loess in loess parent material.

The average weighted organic carbon level of the 0-20 inch layer (OCAV) used in this study was computed from the percent organic carbon in the 0-7 and 7-20 inch layers used by Henao (1976). After reexamining the profile descriptions because there were some discrepancies in naming the A3, A3-B1, and B1 horizons, the depth of A horizon was corrected in several profiles. The erosion classes also were recoded for this study as follows:

0 = no erosion (>30 cm or >12 in. of A horizon),
1 = slight (18-30 cm or 7-12 in. of A horizon),
2 = moderate (7.5-18 cm or 3-7 in. of A horizon with some mixing of A and B horizon), and
3 = severe (<7.5 cm or < 3 in. of A horizon remaining).

Statistical Analysis

To determine the effect of erosion control practices on corn yield, we need to consider the influence of other inputs or variables which act simultaneously in affecting this yield. Either these inputs must be controlled or the study must be designed so that their effects can be separated from the effects of the erosion control practices. If all inputs could be controlled for repeated trials, as in the laboratory or greenhouse, only simple statistical procedures would be necessary. However, such a method is not possible for a study of this nature. Therefore, a method of analysis was employed here that allows the separation of the effects on yield of different variables or groups of variables from each other, but with some restrictions because of intercorrelations.

Multiple regression analysis was used to provide estimates of the effects of many variables[1] on corn yields. All computations were carried out with respect to the model.

$$Y_i = B_0 + B_1X_{1i} + B_2X_{2i} + \dots + B_pX_{pi} + \epsilon_i \quad ,$$

which is the usual multiple regression model having Y as the dependent variate, the explanatory factors $X_1, X_2, \dots X_p$ which are independent in the sense that the values that they take arise independently of the equation above, ϵ_i which is the error term because the postulated independent variates do not completely explain Y_i, and the parameters $B_0, B_1, \dots B_p$ which are the population regression coefficients.

The usual assumptions in the regression analyses were: (1) the X_p are fixed variates, (2) for a fixed set of X's, say (X'_p), the Y's associated with this set are NID with mean $E(Y') = u + \sum_{p=1} B_pX_p$ and variance σ^2 (this assumption is required for setting confidence limits or tests of significance), and (3) for any set of X's the variance of Y shall be the same.

The criteria for retention of given variates in the model were: (1) after the t-test for significance was applied to each of the partial regression coefficients, only those

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[1] The term "variable" will refer to a factor under study whose effect in the regression model and analysis may be a function of one or more variates or terms (X_i). "Variate" will refer to a single term included in the multiple regression model and analysis.

were retained in the equation whose probability was less than $\alpha = 0.20$ initially and usually less than $\alpha = 0.10$ in final stages of model selection; (2) if the magnitude of the correlation between independent variables was above 0.80 (from the correlation matrix), then exclusion of one of these variables resulted in relatively little decrease in the percentage of total variance that was explained; and (3) an additional statistic was calculated for all models, the coefficient of multiple determination, R^2, which gave that fraction of the variance in yield, the dependent variate, that was explained by the independent variates used in the model.

In the first stage of the statistical analysis, a series of regression models were developed using the linear terms of the variables to estimate the effects of environment, weather, management, erosion control, and soil variables on corn yields.

In the second stage, squared terms were added and a series of quadratic models were run to estimate the curvilinear effects of the variables on corn yield.

In the third and final stage, selected linear and squared terms for the variables were included in a full model with selected interactions. Because of the number of variables involved, the number of possible interactions between the variables became large and exceeded the 100-variable capacity of the computer program used. Preliminary screening of the interaction terms was performed to select the ones which explained the most yield variance.

The fitting of the multiple regression equations was done by using the computer program, the Helarctos II (Kennedy, 1971). This program is particularly well-adapted to fit models by the least squares method because of its built-in facility to create different functions out of the columns of the X matrix containing a maximum of 100 independent variates. All the regression statistics from the regression analysis were printed in the computer output as options.

RESULTS AND DISCUSSION

A series of regression models were computed to select the most important erosion control, soil, weather, environmental, and management variables for predicting corn yields on the upland soils of western and southwestern Iowa. The source of the data was given in the Materials and Methods section.

The selection of the final regression models involved four stages or series of multiple regression equations as follows:

1. The first stage, designated the MODEL I series, involved the testing and selection of important linear terms.
2. The second stage, the MODEL II series, involved the testing of the quadratic functions of the variables by adding the squared terms to the regression equations and testing the significance of these in the presence of the linear terms.
3. The third stage, designated the MODEL III, IV, and V series, involved the testing and selection of the important linear by linear interaction terms from the large number of possible ones among the many variables. These interactions were selected in the presence of the linear and squared terms selected in the first two series.

4. For the final stages, the MODEL VI and VII series, the most significant interactions from the MODEL III to V series were combined with the selected linear and squared terms from the MODEL I and II series and the most significant terms were selected for predicting corn yield and for studying the effects of the variables on corn yield.

MODEL I Series: Multiple Regressions of Corn Yield on Linear Functions of Selected Variables

The linear effects of 70 selected erosion control, soil, weather, environmental (other than weather), and management variables on corn yield were studied in the MODEL I series of multiple linear regressions. These variables and their symbols, units, means, and ranges are listed in Table 4 and described more completely in Appendix Table A1. The means of the variables for individual counties are given in Appendix Table A2. All of the variables listed in Appendix Table A1, but not included in Table 4, were tested for significance in preliminary multiple regression analyses and deleted from the models used in this study. All of the variables listed in Table 4 were used in the MODEL I series except the total N, P, and K applied in manure plus fertilizer, respectively.

In the initial multiple regression (MODEL I-1), the multiple linear regression of yield on 70 variables and the

Table 4. Symbols, means, and ranges for the variables included in the multiple regressions of corn yield, using data from upland soils in Adams, Cass, Crawford, Harrison, and Woodbury counties

Symbol	Variable[a]	Mean	Range
Y	Corn yield (bu/acre)	98.7	1-155
TREND	Time trend (coded 1957=1 to 1970=14)	7.5	2- 14
PLDEN	Plant density (stalks per 1/100 acre)	133.7	57-252
BARR	Barren stalks (% of total stalks)	5.5	0- 97
RL3	Root lodged stalks (% of total stalks)	12.5	0- 99
CRW	Corn root damage rating	16.5	10- 52
STLODG1	Stalks broken below ear node at harvest (%)	4.4	0- 52
CB1	First brood corn borer (cavities/10 stalks)	3.4	0- 43
CB2	Second brood corn borer (cavities/10 stalks)	19.6	0- 99
WEEDS	Total grassy + broad leaf weeds (lb/1/10 acre)	54.8	0-424
CULT	Total times, harrowed, rotary hoed, and cultivated	4.1	0- 8
CPLOW	Field plowed on contour (0=no, 1=yes)	0.46	0- 1
CPLANT	Field planted on contour (0=no, 1=yes)	0.57	0- 1
DTERR	Distance to top of terrace above site (coded 200'-distance)	14.8	0-178
YCPLOW	Years contour plowed	6.2	0- 34
YCPLANT1	Years contour planted (contoured and terraced sites)	7.5	0- 34
YCPLANT2	Years contour planted (contoured sites, only)	5.4	0- 29
YTERR	Years since terrace was built	1.48	0- 34
SPRPLOW	Plowed (fall plowed=0, spring plowed=1)	0.88	0- 1
NONPLOW	Other tillage (plowed=0, others=1)	0.03	0- 1
TILLAFT	Number of tillage operations after plowing	3.4	0- 9

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[a] More complete descriptions of the variables, their units, and coding used are given in Appendix Table A1.

Table 4. (Continued)

Symbol	Variable	Mean	Range
PLDATE	Planting date (days after April 20)	25.8	6-54
SLKDATE	75% silking date (days after June 30)	30.5	15-50
ROWWID	Average row width (coded, width - 28 in.)	12.0	2-18
MANURE	Manure rate (tons/acre)	1.9	0-22
N	Total N in manure and fertilizer (lb N/acre)	60.5	0-236
P	Total P in manure and fertilizer (lb P/acre)	14.9	0-78
K	Total K in manure and fertilizer (lb K/acre)	20.8	0-196
NFERT	N fertilizer rate (lb N/acre)	51.1	0-236
PFERT	P fertilizer rate (lb P/acre)	10.8	0-60
KFERT	K fertilizer rate (lb K/acre)	5.2	0-83
NCODE	Cropping sequence code for N availability	20.2	8-40
KCODE	Cropping sequence code for K availability	18.8	0-60
NRES1	Total N applied in previous year (lb N/acre)	28.7	0-243
PRES1	Total P applied in previous year (lb P/acre)	8.4	0-79
PRES2	Total P applied 2 years previous (lb P/acre)	8.7	0-79
PRES3	Total P applied 3 years previous (lb P/acre)	7.0	0-79
SLOPE	% slope of site	8.4	1-21
SLRATIO	Slope ratio (% row slope/% site slope)*100	31.0	0-99
ASPECT	Aspect of site (coded 1-9)	4.5	1-9
ROWDIR	Row direction (coded 1-9)	5.6	1-9
PH1	Soil pH of plow layer (actual pH*10)	65.7	51-81
PHB	Buffer pH (buffer pH-6.00)*100	73.4	5-99
STN	Soil test N, field moist (pp2m)	61.9	28-99
STP1	Soil test P (pp2m)	22.4	5-90
STK1A	Soil test K, field moist (pp2m)	238.9	70-350
TWP	Township number (N-S direction)	80.2	71-89
RANGE	Range number (E-W direction)	38.8	32-47
SLCONF	Slope configuration (coded 1 to 6)	2.4	1-5
EROS	Erosion class (coded 0 to 3)	1.33	0-3
DAHOR	Depth of A horizon (inches)	9.3	0-22

Table 4. (Continued)

Symbol	Variable	Mean	Range
OCAV	Wtd average organic C, 0-20 inch layer (% OC*10)	11.5	3- 22
DRAIN	Internal drainage (coded 10 to 90)	34.8	30- 70
PERM	Subsoil permeability (coded 10 to 90)	51.7	35- 90
CPL	% clay in plow layer	26.7	16- 36
CMAX	Maximum % clay in subsoil	31.0	16- 55
DCMAX	Depth to midpoint of maximum clay horizon (inches)	17.4	7- 57
BIO	Biosequence (coded 1=forest to 5=prairie)	4.95	3- 5
BD2	Bulk density at 30-40" deep (coded (BD-1.00)*100)	33.4	25- 73
DPMT	Depth to till parent material (coded 60"-depth)	3.1	0- 60
DPMP	Depth to paleosol (coded 60"-depth)	2.5	0- 48
DPML/T	Depth to till below loess (coded 60"-depth)	0.5	0- 42
DPML	Depth to deoxidized loess (coded 60"-depth)	6.1	0- 54
PHMIN	Minimum pH in subsoil (coded pH*10)	66.7	54- 82
DPHMIN	Depth to midpoint of minimum pH layer (inches)	11.3	6-38
DCAL	Depth to top of carbonate layer (coded 60"-depth)	15.8	0-54
PH3	pH of 30-42" layer (coded pH*10)	71.9	59- 83
STP3	Soil test P of 30-42" layer (pp2m)	17.0	5- 82
STK2	Soil test K of 12-24" layer (pp2m)	59.8	24-166
EM3V	Excess moisture index	1.11	0- 16.0
DEFCTV(DV)	Moisture stress index	2.50	1.10- 3.38
PPT75	Total rainfall for 42 days before silking to 33 days after (inches)	9.5	2.1 - 18.0
PPTEAR	Total rainfall from April 15 to 42 days before silking (inches)	9.3	1.9 - 20.3
PAWC	Plant available water capacity (in./5 ft)	11.1	7.1 - 12.1
PAW	Plant available water on April 15 (in./5 ft)	7.1	1.0 - 11.4

correlation matrix (all simple correlation coefficients between variables) were computed. The criteria for selection of the variables to be retained for testing in subsequent regression models, as given by Henao (1976), were based on:

1. The magnitude of the correlation or degree of intercorrelation between the "independent" variables,
2. Significance levels[1] of the partial regression coefficients of the variables as indicated by the t-test,
3. The coefficient of multiple determination, R^2-value, which is the fraction of yield accounted for by the variables in the regression model, and
4. The logical value of the variables for predicting yield and for determining the effects of the variables on yield.

<u>Correlation analysis</u>

The correlation matrix was first examined to determine the simple correlations (r-values) between yield and each of the variables. The highly significant correlations between

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[1] Significance level refers to the significance probability level as determined by a statistical test. The terms "highly significant" and "significant" will refer to significance levels of 0.01 or smaller (1% level) and between 0.01 and 0.05 (5% level), respectively. Significance at other levels will be referred to as "significance at the 0.10 or 10% level" etc. In the tables, significance at the 0.01, 0.05, 0.10, and 0.15 levels will be designated by **, *, ++, and +, respectively.

yield and the variables are listed in Table 5. Simple correlations show best the relationships between yield and the dominant variables affecting yield. A variable may still have a significant effect in a multiple regression, although its simple correlation with yield is not significant. Variables which had highest correlations with yield (>±0.24) included BARR (barren stalks), SLKDATE (silking date), PLDEN (plant density), and N (total N from manure and fertilizer) and the soil variables of EROS (erosion class), DAHOR (depth of A horizon), OCAV (average organic carbon in surface 20 inches), STN (soil test N of plow layer), STP1 (soil test P of the plow layer), PH1 (pH of the plow layer), PHMIN (minimum pH in the subsoil), PH3 (pH of the 30-42 inch zone), DCAL (depth to top of calcareous horizon), and STP3 (soil test P of the 30-42 inch zone).

The many simple correlations greater than r = ±0.39 between the variables are listed in Appendix Table A3. The magnitudes of the higher correlations within related groups of variables are shown in Table 6. These show the degree of correlation between the so-called "independent" variables. The organic matter related variables (EROS, DAHOR, and OCAV) were highly intercorrelated and slope was also highly correlated with each of these. The subsoil variables of PHMIN, STP3, and STK2 also were correlated with the organic matter related variables. Most of the clay related variables were very highly correlated. Minimum pH in the subsoil (PHMIN)

Table 5. Simple correlations (r-values) greater than ±0.10 between corn yield and listed variables

Variable	f[a]	Variable	r	Variable	r
TREND	.15	NFERT	.24	SLCONF	.15
PLDEN	.35	PFERT	.19	EROS	.27
BARR	-.53	KFERT	.18	DAHOR	.28
CRW	-.11	NRES1	.12	OCAV	.32
CB1	.13	PRES2	.15	CPL	.22
CPLANT	-.12	SLOPE	-.23	CMAX	.16
PLDATE	-.16	PH1	-.26	DPMP	-.15
SLKDATE	-.35	PHB	-.18	PHMIN	-.30
ROWWID	.17	STN	.30	DCAL	-.29
MAN	.12	STP1	.25	PH3	-.30
N	.28	STK1A	.23	STP3	.30
P	.24	TWP	-.11	STK2	.13
K	.16	RANGE	-.19	DV	.18

[a] For n = 622, r-value of 0.11 is significant at the 0.01 level.

was also highly correlated with most of these variables.

The soil pH related variables in the plow layer and subsoil and the available subsoil P (STP3) were very highly intercorrelated and also were highly correlated with the clay variables, CPL and CMAX (Table 6). The location variables, TWP (N-S direction) and RANGE (E-W direction), were very highly correlated because the sites were located near a SE-NW line through Adams, Cass, Harrison, Crawford, and Woodbury counties. The higher correlations between RANGE and soil variables than between TWP and soil variables showed that soil parameters varied more in an E-W than in a N-S direction.

The high correlation between many of the location and

Table 6. Simple correlation coefficients (r-values) between variables within related groups, MODEL I series[a]

Variable	Organic matter related variables						
	SLCONF	EROS	DAHOR	OCAV	PHMIN	STP3	STK2
SLOPE	-	.62	-.66	-.67	.51	-	-.42
SLCONF	-	-.43	.50	.45	-	-	-
EROS		-	-.93	-.90	.62	-.45	-.50
DAHOR			-	.94	-.61	.51	.64
OCAV				-	-.67	.53	.59

Variable	Clay related variables						
	PERM	CPL	CMAX	DCMAX	BD2	PAWC	PHMIN
DRAIN	.76	.48	.73	.47	.54	-.52	-.42
PERM	-	.68	.96	.61	.77	-.78	-.63
CPL		-	.78	-	.43	-.44	-.79
CMAX			-	.60	.63	-.65	-.77
DCMAX				-	-	-	-
BD2					-	-.95	-

Variable	Soil pH related variables						
	PHB	PHMIN	DCAL	PH3	STP3	CPL	CMAX
PH1	.88	.90	.79	.71	-.47	-.71	-.66
PHB	-	.76	.61	.62	-	-.51	-.53
PHMIN		-	.87	.84	-.60	-.79	-.77
DCAL			-	.92	-.63	-.70	-.66
PH3				-	-.74	-.64	-.64

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[a] Only the correlation coefficients greater than ± 0.39 are shown.

Table 6. (Continued)

Variable	Erosion control variables					
	CPLANT	DTERR	YCPLOW	YCPLANT1	YTERR	SLRATIO
CPLOW	.78	-	.72	.68	-	-.50
CPLANT	-	-	.58	.70	-	-.63
DTERR		-	-	-	.70	-
YCPLOW			-	.88	.46	-
YCPLANT1				-	.43	-.59

Variable	Management related variables						
	PLDEN	NFERT	PFERT	KFERT	NCODE	NRES1	PRES1
TREND	.56	.53	.47	.48	-	-	-
PLDEN	-	.48	.40	-	-	-	-
NFERT		-	.64	.51	.45	.51	-
PFERT			-	.56	-	-	-
NCODE					-	.61	.41
KCODE					-.55	-	-
NRES1						-	.72

Variable	Location variables						
	RANGE	PH1	DRAIN	PERM	CMAX	BD2	PHMIN
TWP	.84	-	-.62	-.56	-.58	-.43	.47
RANGE	-	.50	-.68	-.74	-.77	-.56	.64

Variable	Miscellaneous variables						
	SLKDATE	STP1	STK1A	STK2	PAWC	PPT75	PPEAR
PLDATE	.60	-	-	-	-	-	-
STN	-	.42	.45	-	-	-	-
STP1		-	.49	-	-	-	-
STK1A			-	.58	-	-	-
EM3V				-	-.69	-	-
DV						.50	.44

soil variables were expected because most of the sites were on the deep loess soils of the Monona-Ida, Marshall, and Shelby-Sharpsburg-Macksburg soil association areas. Hutton (1948) and Ulrich (1949) studied these soils and found that they developed in loess originating from a common source in the Missouri bottomlands and that their morphology and genesis changed with distance from the source.

Soil erosion control variables involving contour plowing and contour planting were highly correlated because most of the fields contour planted were also contour plowed. The terrace variables were highly correlated with each other but less with the contouring variables because fewer of the sites were terraced. The correlations between the contouring variables and SLRATIO were high.

Several of the management variables were highly correlated. During the period of study, plant density and fertilizer levels increased as shown by the correlations with TREND (Table 6). The farmers used similar ratios of N, P, and K fertilizers, particularly in later years, which caused the high correlations between the fertilizer nutrients in the first year and then between their residual levels. A few other variables were highly correlated as shown in the last part of Table 6.

The high correlations between many of the variables complicated the variable selection for multiple regression analyses. However, these high correlations were expected in a soil productivity study using randomly selected sites; one can only select variables to minimize the correlations although some highly correlated variables are of interest.

If the correlations are very high (greater than ±0.7), there is little advantage to having both correlated variables in the same regression. In these cases, usually only one variable of the pair was retained for further testing. If the correlations are greater than ±0.5, the partial regression coefficients in the regression equations of the associated correlated variables frequently are distorted and, if greater than ±0.6, the regression coefficients usually are distorted (Henao, 1976). If the correlations were between ±0.5 to 0.7, both variables frequently were retained for further testing in alternative models. The effects of correlated variables are of little importance if the regressions are to be used for yield prediction only; these effects are important and must be considered if the effects of the variables on yield are to be determined at fixed levels of the other correlated variables.

Multiple linear regression analyses

MODELS I-1 and I-2 All variables were included in the first model, MODEL I-1. These gave an R^2 of 0.765 (Table 7) which indicated that 76.5% of the corn yield variation was explained by the 70 variables in the model. The significance level of each variable is shown by its t-value

Table 7. R^2-values for the multiple linear regressions of yield on selected variables, MODEL I series

MODEL	No. of variables	Variables deleted	R^2
I-1	70	-	0.765
2	68	BARR, SLKDATE from MODEL I-1	0.521
3	54	CULT, SPRPLOW, NRES1, PRES3, ASPECT, PHB PERM, BD2, DPMP, DPHMIN, PH3, PPT75, PPTEAR, PAW from MODEL I-2	0.502
4	49	DAHOR, OCAV, CMAX, PHMIN, DCAL from MODEL I-3	0.486
6	45	CPLANT, DTERR, YCPLOW, YCPLANT from MODEL I-4; CPLOW, YTERR tested	0.479
7	46	DTERR, YCPLOW, YCPLANT from MODEL I-4; CPLOW, CPLANT, YTERR tested	0.479
8	46	CPLANT, YCPLOW, YCPLANT from MODEL I-4; CPLOW, DTERR, YTERR tested	0.481
9	46	CPLANT, DTERR, YCPLANT from MODEL I-4; CPLOW, YCPLOW, YTERR tested	0.482
10	46	CPLANT, DTERR, YCPLOW from MODEL I-4; CPLOW, YCPLANT, YTERR tested	0.481

(ratio of the partial regression coefficient and its standard error) which is listed in Table 8. All of the variables, other than the soil variables, that had the highest simple correlations with yield (Table 5) also had significant effects on yield in the multiple regression. However, several variables (CRW, WEEDS, DTERR, YCPLOW, YTERR, TILLAFT, MAN, NCODE, and KCODE) had significant effects in the multiple

Table 8. Significance of the variables as shown by their t-values, MODEL I series[a]

Variable	t-values of variables in MODEL			
	I-1	I-2	I-3	I-4
TREND	0.99	-0.95	-0.05	0.11
PLDEN	9.44**	5.25**	5.77**	5.44**
BARR	-22.25**	-	-	-
RL3	0.69	-2.49*	-2.42*	-2.10*
CRW	-2.65**	-3.80**	-3.53**	-3.52**
STLODG1	-1.38	-1.12	-0.88	-1.10
CB1	0.39	-0.76	-0.41	-0.25
CB2	1.10	1.63+	1.87++	2.01*
WEEDS	-3.77**	-2.65**	-2.77**	-2.71**
CULT	-0.61	-0.01	-	-
CPLOW	0.85	1.47	1.39	1.40
CPLANT	-0.58	-0.61	-0.39	-0.56
DTERR	-3.48**	-1.47+	-1.59+	-1.68++
YCPLOW	-1.98*	-2.08*	-2.09*	-1.96*
YCPLANT	1.34	0.71	0.67	0.62
YTERR	2.29*	0.62	0.89	1.10
SPRPLOW	0.15	-0.30	-	-
NONPLOW	-1.17	-0.72	-0.87	-0.52
TILLAFT	-2.34*	-0.73	-0.91	-1.04
PLDATE	2.34*	-1.57+	-2.05*	-1.77++
SLKDATE	-6.41**	-	-	-
ROWWID	-1.20	-0.75	-0.79	-0.71
MAN	3.03**	3.29**	3.25**	2.88**
NFERT	3.23**	3.31**	3.90**	4.50**
PFERT	2.12*	1.85++	1.75++	1.47+
KFERT	0.76	0.66	-0.09	-0.29
NCODE	-3.36**	-2.92**	-3.17**	-3.21**
KCODE	2.18*	1.37	1.43	1.37
NRES1	1.44	0.71	-	-
PRES1	0.81	1.51+	1.97*	1.67++
PRES2	1.21	1.70++	1.50+	1.43
PRES3	0.98	0.60	-	-
SLOPE	0.67	-0.42	-0.24	-0.85
SLRATIO	-0.14	-0.76	-0.74	-1.05
ASPECT	0.31	0.08	-	-

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[a] For n = 622, t = 2.60, 1.97, 1.65, and 1.48 for the 1, 5, 10, and 15% significance levels, respectively. These are designated by **, *, ++, +, respectively, in this and all other tables.

Table 8. (Continued)

Variable	t-values of variables in MODEL			
	I-1	I-2	I-3	I-4
ROWDIR	0.39	0.62	0.38	-0.12
PH1	-1.99*	-1.64++	1.86++	-0.09
PHB	3.20**	3.65**	-	-
STN	4.55**	4.48**	5.19**	5.59**
STP1	-0.17	-1.33	-0.45	-0.60
STK1A	0.66	1.17	0.66	1.13
TWP	0.85	0.43	-0.13	-0.88
RANGE	-1.25	-1.05	-0.69	-1.05
SLCONF	2.04*	2.21*	1.95++	1.51+
EROS	-0.14	0.26	-0.44	0.48
DAHOR	-0.44	-0.47	-0.30	-
OCAV	0.34	0.04	-1.07	-
DRAIN	-0.43	-0.85	-1.32	-0.99
PERM	0.17	0.56	-	-
CPL	-0.53	-0.65	0.21	2.66**
CMAX	0.56	1.42	2.52*	-
DCMAX	-1.07	-1.38	-0.85	0.09
BIO	-1.28	-1.13	-1.57+	-2.19*
BD2	-0.21	-0.11	-	-
DPMT	-0.30	1.25	3.60**	1.54++
DPMP	-1.88++	-0.41	-	-
DPML/T	0.16	0.69	0.80	0.80
DPML	2.13*	1.67++	1.16	0.45
PHMIN	-0.57	-0.78	-0.66	-
DPHMIN	-0.36	-0.55	-	-
DCAL	-0.06	-0.46	-2.20*	-
PH3	-0.15	-0.22	-	-
STP3	-0.00	-0.45	-0.25	0.96
STK2	1.22	1.25	1.02	-0.58
EM3V	-0.85	-1.25	-1.95++	-1.90++
DV	6.27**	7.97**	9.29**	9.29**
PPT75	-0.40	-1.66++	-	-
PPTEAR	-0.47	-1.87++	-	-
PAWC	0.34	2.84**	4.25**	2.84**
PAW	-0.23	-1.05	-	-

regression but were only slightly correlated with yield. This illustrates that selection of variables by their simple correlations with yield is a poor method. Of the 14 soil variables most highly correlated with yield (r-values greater than ±0.17), only three (PH1, PHB, and STN) had a significant effect on yield at the 5% level. The high correlations among many of the soil variables thus complicate selection of these variables for multiple regression models (Henao, 1976).

In MODEL I-2, deletion of the BARR and SLKDATE variables markedly reduced the R^2 from 0.765 to 0.521 (Table 7). This effect agrees with the results of Voss (1969). Morris (1972), and Henao (1976). Deletion of these two variables increased the significance of RL3, PRES1, PRES2, PAWC, and the rainfall variables and decreased the significance of DTERR, YTERR, KCODE, and DPMP. Although the barren stalks and silking date variables are highly related to yield, they are poor predictors of yield in general regression equations except for special cases. Most of the variable selection in this study will be in the absence of these variables as was done by Henao (1976).

MODELS I-3 and I-4 For MODEL I-3, 14 variables were deleted from MODEL I-2 as shown in Table 7. Some of these had very low significance in the previous models, some were soil variables which had very high correlations with others in the related groups of variables (Table 6), and three were the simple weather variables which were originally included to compare with the sophisticated EM3V and DV indexes computed by Morris (1972) and Henao (1976). Deletion of these 14 variables decreased the R^2 from 0.52 to 0.50 (Table 7). The variables that increased in significance included PLDATE, CMAX, DPMT, DCAL, and EM3V (Table 8).

For MODEL I-4 five soil variables were deleted from MODEL I-3 to determine the effects on the variables retained with which these variables were highly correlated. The R^2 was decreased to 0.486 (Table 7). The only marked changes in MODEL I-4 were that the significance of CPL was increased and that of PH1 was decreased.

MODELS I-6 to I-10 In this series of models, various combinations of the six contouring and terracing variables were tested as shown for MODELS I-6 to I-10 in Table 7. The CPLOW, CPLANT, and YTERR had very little significance in any of the models but the DTERR and YCPLANT variables were significant at about 20% level and YCPLOW was significant at the 5% level. Since the effects of the erosion control variables on yield are of primary interest, all except one were retained for further testing in the quadratic MODEL II series.

Variables deleted Twenty (20) of the variables were deleted at this stage and 50 variables were retained for further testing in the quadratic MODEL II series. Nine of the variables had little significance in MODEL I, had little correlation with any of the other variables, and were not expected to have any marked curvilinear effects; these included CULT, SPRPLOW, NONPLOW, ROWWID, ASPECT, ROWDIR, DPML/T, DPML, and DPHMIN. Others were deleted because they had little significance in MODEL I, and were very highly correlated with variables which had greater significance in MODEL I and were of more interest in this study. These 10 variables included TREND, NRES1, PRES3, TWP, PERM, DCMAX, BD2, DPMP, PH3, and STK2. One of the erosion control variables, CPLANT, was deleted because it was highly correlated with CPLOW (r = 0.78) which had more significance in the MODEL I series.

Many of the variables retained had significance at the 1 to 15% level. Others such as CB1, PH1, and EROS were retained because Henao (1976) found that they had marked curvilinear effects on yield but were not significant in linear models. Many of the soil variables had little significance in MODEL I in the presence of other variables with which they were highly correlated but were retained to test in alternative models.

MODEL II Series: Multiple Regressions of Corn Yield on Quadratic Functions of Selected Variables

The objective of this series of regressions was to test and select the management, erosion control, weather, soil and environmental variables that had significant quadratic or curvilinear effects on yield. Selection of variables based only on their linear effects on yield may be erroneous because some variables exhibit strong curvilinear effects in quadratic models but little or no significant linear effects in linear models. This occurs particularly if yield increases to a maximum and then decreases as the level of the variable increases.

Therefore, for the MODEL II series, 48 variables selected from MODEL I series and their squared variates were included along with the linear variates only for CPLOW and BIO (Table 9). After testing the two erosion control variables in MODELS II-12 to 18, the YCPLANT2 variable was added. The combined effects of all three erosion control variables were then tested.

MODELS II-1 and II-2

All 98 variates tested in MODEL II-1 gave an R^2 of 0.819 (Table 10). The squared terms were significant at the 5% level for the following variables: PLDEN, BARR, RL3, CB1, CB2, YCPLANT, YTERR, PLDATE, NCODE, SLRATIO, STP1, EROS, OCAV, DRAIN, STP3, and DV. Their linear variates were also significant at the 10% to 1% levels.

Deletion of BARR and SLKDATE and their squared terms from MODEL II-1 caused the usual drastic reduction in R^2 from 0.819 in MODEL II-1 to 0.658 in MODEL II-2 (Table 10). This was also accompanied by increases in the significance

Table 9. Variates included in the multiple regressions of corn yield on the quadratic functions of selected variables, MODELS II-1 to II-18

X_i	Variate	X_i	Variate	X_i	Variate
1	Y	34	SLCONF	67	MAN^2
2	PLDEN	35	EROS	68	NFERT^2
3	BARR	36	DAHOR	69	PFERT^2
4	RL3	37	OCAV	70	KFERT^2
5	CRW	38	DRAIN	71	NCODE^2
6	STLODG1	39	CPL	72	KCODE^2
7	CB1	40	CMAX	73	PRES1^2
8	CB2	41	BIO	74	PRES2^2
9	WEEDS	42	DPMT	75	SLOPE^2
10	CPLOW	43	PHMIN	76	SLRATIO^2
11	DTERR	44	DCAL	77	PH1^2
12	YCPLOW	45	STP3	78	PHB^2
13	YCPLANT1	46	EM3V	79	STN^2
14	YTERR	47	DV	80	STP1^2
15	TILLAFT	48	PPT75	81	STK1A^2
16	PLDATE	49	PPTEAR	82	RANGE^2
17	SLKDATE	50	PAWC	83	SLCONF^2
18	MAN	51	PAW	84	EROS^2
19	NFERT	52	PLDEN^2	85	DAHOR^2
20	PFERT	53	BARR^2	86	OCAV^2
21	KFERT	54	RL3^2	87	DRAIN^2
22	NCODE	55	CRW^2	88	CPL^2
23	KCODE	56	STLODG1^2	89	CMAX^2
24	PRES1	57	CB1^2	90	DPMT^2
25	PRES2	58	CB2^2	91	PHMIN^2
26	SLOPE	59	WEEDS^2	92	DCAL^2
27	SLRATIO	60	DTERR^2	93	STP3^2
28	PH1	61	YCPLOW^2	94	EM3V^2
29	PHB	62	YCPLANT1^2	95	DV^2
30	STN	63	YTERR^2	96	PPT75^2
31	STP1	64	TILLAFT^2	97	PPTEAR^2
32	STK1A	65	PLDATE^2	98	PAWC^2
33	RANGE	66	SLKDATE^2	99	PAW^2

Table 10. R^2-values for multiple regressions of yield on selected variates, MODEL II series

Model no.	No. of X variates	Variates deleted	R^2
II-1	98	-	0.819
-2	94	BARR and SLKDATE variables deleted from MODEL II-1	0.658
-3	76	PHB, DAHOR, OCAV, CMAX, PHMIN, DCAL, PPT75, PPTEAR, and PAW variables (linear and squared variates) deleted from MODEL II-2	0.643
-12	53	TILLAFT, KCODE, PRES2, RANGE, and SLCONF variables, BIO (linear only), and squared variates of RL3, STLODG1, WEEDS, YCPLOW, MAN, KFERT, PRES1, SLOPE, STK1A, DPMT, EM3V, and PAWC deleted from MODEL II-3	0.632
-18	49	CPLOW, DTERR, DTERR^2, and YCPLOW variates deleted from MODEL II-12	0.623

level of CRW, PFERT, PH1, STN, DCAL, and PPTEAR. The variables that decreased in significance included RL3, STLODG1, and SLRATIO.

MODELS II-3 to II-12

In this series of models, the most highly correlated variables in the soil pH, organic matter, clay, and moisture stress groups of related variables were tested in alternative models. The procedure used was to delete the related variable or variables within each group except the one or ones to be tested. For MODEL II-3, the linear and squared variates of the following variables were deleted from MODEL II-2: PHB, PHMIN, and DCAL of the pH related variables, OCAV and DAHOR of the organic matter related variables, CMAX of the clay related variables, and PPT75, PPTEAR, and PAW of the weather related variables. The variables retained for MODEL II-3, the base model, included PH1, EROS, CPL, and DV. In the MODEL I series and in MODEL II-2, each of these variables appeared to be the most important one in its group of related variables.

In MODEL II-3, deletion of the 18 variates decreased the R^2 from 0.658 to 0.643 (Table 10). The four pH related variables were tested in alternative MODELS II-3, -4, -7, and -8 as shown in Table 11. PH1 was the most important variable as shown by the slightly higher R^2 of MODEL II-3 and by the highly significant t-values of its linear and squared variates.

Alternative MODELS II-3, -5, and -6 were used to test the three organic matter related variables (EROS, DAHOR, and OCAV). The EROS variable was selected as the best one because the R^2 of MODEL II-3 was slightly higher and the t-values of its linear and squared variates had higher significance (Table 11). The EROS variable, although only a semiquantitative variable, is useful because the soils are mapped by erosion classes. The effects of the DAHOR and OCAV variables, however, may not be described very well by the quadratic function; it forces yields to decrease beyond the level which

Table 11. Regression statistics for testing correlated variables in related groups of variables, MODEL II series

Model no.	No. of X variates	Variable(s) in related group[a]		t-values of variate tested		R^2
		Deleted	Tested	Linear	Squared	
II-3	76	PHB, PHMIN, DCAL	PH1	2.85**	-2.67**	0.643
-4	76	PH1, PHMIN, DCAL	PHB	0.48	0.21	0.640
-7	76	PH1, PHB, DCAL	PHMIN	0.75	-0.73	0.635
-8	76	PH1, PHB, PHMIN	DCAL	-1.48+	0.90	0.637
II-3	76	DAHOR, OCAV	EROS	1.59+	-1.58+	0.648
-5	76	EROS, OCAV	DAHOR	0.33	-0.38	0.641
-6	76	EROS, DAHOR	OCAV	-0.38	-0.42	0.641
II-3	76	CMAX	CPL	2.08*	-2.21*	0.643
-9	76	CPL	CMAX	0.25	0.18	0.641
II-3	76	PPT75, PPTEAR, PAW	DV	4.41**	-3.23**	0.643
-10	80	DV	PPT75	1.56+	-1.02	0.600
			PPTEAR	2.98**	-2.14*	
			PAW	1.65++	-1.02	
-11	72	DV, EM3V, PPT75 PPTEAR, PAW	-	-	-	0.577

[a] Both the linear and squared variates of the variable were deleted or tested.

gives the maximum yield although, actually, yields may not decrease at the higher DAHOR and OCAV levels.

The CPL variable gave a slightly higher R^2 than the CMAX variable in alternative MODELS II-3 and -9 (Table 11). The t-values of the linear and squared terms of CPL were significant but those of CMAX were not.

The effect of the moisture stress index, DV, computed by the sophisticated method proposed by Shaw (1963) and modified by Morris (1972) and Henao (1976) was compared with the rainfall measurements, PPT75 and PPTEAR, and the estimated plant available water on April 15, PAW, in MODELS II-3 and -10. As shown in Table 11, deletion of the highly significant variates for DV markedly reduced the R^2. The three variables (PPT75, PPTEAR, and PAW) had significant effects on yield at the 15% and 1% levels in MODEL II-10. Deletion of these three variables in MODEL II-11 caused a further decrease in R^2 (Table 11). These could be useful variables if the weather indexes were not computed.

After testing the correlated variables in MODELS II-3 to -11, 17 of the nonsignificant squared terms were deleted from MODEL II-3 to observe the effects of these deletions on the significances of the linear terms retained and six nonsignificant linear terms were also deleted. Deletion of the nonsignificant 23 variates decreased the R^2 of MODEL II-12 slightly (Table 10).

Henao (1976), using data not coded around their means, had observed that, if the curvilinear effect of a variable is slight, the addition of its squared term to the model frequently decreased the significance of the linear term markedly. Deletion of the squared terms increased the significance of the linear terms from nonsignificance in MODEL II-3 to the 5% or 1% level for the RL3, STLODG1, WEEDS, KFERT, PRES1, EM3V, and PAWC variables in MODEL II-12. The MAN, SLOPE, and DPMT linear terms increased slightly in significance but not to the 5% level.

MODELS II-13 to II-18

Each of the two terracing variables (DTERR and YTERR) were tested with each of the remaining contouring variables (CPLOW, YCPLOW, and YCPLANT1) in MODELS II-13 to -18 as shown in Table 12. The CPLANT variable had been deleted after testing in the MODEL I series and the squared variate of the YCPLOW variable was deleted in MODEL II-12. Because of the high correlations within the contouring groups of variables and between the two terracing variables (Table 6). only one variable from each group was retained for further testing. With MODEL II-12 serving as the base model, one of the terracing and two of the contouring variables were deleted in alternative models to test all possible combinations of one variable from each group.

The combination of the YCPLANT1 and YTERR variables in MODEL II-18 gave a slightly higher R^2 than any other combina-

Table 12. Regression statistics for the erosion control variables in alternative models, MODELS II-12 to II-18

Model no.	No. of X variates	Variables[a]		t-values of variates tested		R^2
		Deleted	Tested	Linear	Squares	
II-12	53	-	-	-	-	0.632
-13	48	YCPLOW, YCPLANT, YTERR	CPLOW,	-0.42	-	0.617
			DTERR	-0.72	0.43	
-14	48	CPLOW, YCPLANT, YTERR	YCPLOW,	-0.30	-	0.617
			DTERR	-0.71	0.42	
-15	49	CPLOW, YCPLOW, YTERR	YCPLANT,	-0.51	0.27	0.618
			DTERR	-0.66	0.38	
-16	48	DTERR, YCPLOW, YCPLANT	CPLOW,	-1.00	-	0.621
			YTERR	1.88++	-2.54*	
-17	48	CPLOW, DTERR, YCPLANT	YCPLOW,	-0.14	-	0.620
			YTERR	1.71++	-2.40*	
-18	49	CPLOW, DTERR, YCPLOW	YCPLANT,	-1.84++	1.73++	0.623
			YTERR	2.20*	-2.93**	

[a] Variables deleted or tested included their linear and squared (if present) variates.

tion and was the only model in which a contouring variate had any significance (Table 12). Another advantage of this combination is that the correlation between the two variables was only 0.41 (Table 6). Addition of the regression coefficients of these two variables gives the cumulative effect of terracing on yield, as will be discussed next. No estimate of the unconfounded effect of contour planting was possible in these models.

MODELS II-34 to II-47

As discussed in the Materials and Methods section, individual coefficients of the YCPLANT1 and YTERR variates did not give unconfounded effects of contour planting and terracing in MODELS II-1 to -18. This was because the YCPLANT1 variable compared contoured only (years) plus terraced sites (years) vs the noncontoured sites (years=0) and YTERR compared terraced sites (years) vs contour planted (years=0) and noncontoured sites (years=0). At this stage of testing, a transformed variable, YCPLANT2, was added which compared contour planted sites (years) vs terraced (years=0) and noncontoured sites (years=0). The coding and uses of this variable to obtain unconfounded cumulative effects of contour planting and terracing were previously discussed in the Materials and Methods section. The summation of the regression coefficients for YCPLANT1 and YCPLANT2 gave the contour planting effect and the sum of those for YCPLANT1 and

YTERR gave the terracing effect. The other alternative method previously discussed was to delete the data from all of the terraced sites and then the data from all of the sites that were only contour planted to determine the unconfounded effects of the two erosion control practices.

The linear and squared terms of YCPLANT2 and the linear RANGE variate were added to MODEL II-18 and the MAN variable was deleted; the new set of variates is given in Table 13. The YCPLANT2 variable was highly correlated with YCPLANT1 ($r=0.73$) and SLRATIO ($r=-0.45$). The alternative procedures for testing the erosion control practices are outlined in Table 14.

In the first model, MODEL II-34, an R^2 of 0.626 was obtained (Table 14). The YTERR variates were highly significant but only the YCPLANT1 and YCPLANT2 linear variates were significant at the 0.10 level (Table 15). In this model, the combined coefficients for years of contour planting were -0.096 for the linear ($b_1 + b_2$) and 0.009 for the quadratic ($b_{11} + b_{22}$) effects. The regression coefficients for years of terracing were 0.858 for the linear ($b_1 + b_3$) and -0.049 for the quadratic ($b_{11} + b_{33}$) effects.

In MODEL II-36, YCPLANT2 was deleted from MODEL II-34 to test the terracing effect disregarding the contour planting effect. The summed regression coefficients for the terracing effect were 0.689 and -0.042 for the linear and squared terms, respectively; these were similar to those in MODEL II-34

Table 13. Variates included in the multiple regressions of corn yield on selected variables, MODELS II-34 to II-48

X_i	Variate	X_i	Variate	X_i	Variate
1	Y	19	SLRATIO	36	CB2^2
2	PLDEN	20	PH1	37	YCPLANT1^2
3	RL3	21	STN	38	YCPLANT2^2
4	CRW	22	STP1	39	YTERR^2
5	STLODG1	23	STK1A	40	PLDATE^2
6	CB1	24	RANGE	41	NFERT^2
7	CB2	25	EROS	42	PFERT^2
8	WEEDS	26	DRAIN	43	NCODE^2
9	YCPLANT1	27	CPL	44	SLRATIO^2
10	YCPLANT2	28	DPMT	45	PH1^2
11	YTERR	29	STP3	46	STN^2
12	PLDATE	30	EM3V	47	STP1^2
13	NFERT	31	DV	48	EROS^2
14	PFERT	32	PAWC	49	DRAIN^2
15	KFERT	33	PLDEN^2	50	CPL^2
16	NCODE	34	CRW^2	51	STP3^2
17	PRES1	35	CB1^2	52	DV^2
18	SLOPE				

(Table 15). The contour planting effect, disregarding the terrace effect, was tested in MODEL II-37 by deleting the YTERR variates. The summed regression coefficients for the linear and quadratic terms were -0.063 and 0.015, respectively. and were similar to those in MODEL II-34. All of the erosion control variables were deleted in MODEL II-41 which dropped the R^2 to 0.617 (Table 14) showing that these erosion control practices were accounting for only 1% of the variations in corn yield in the quadratic model.

The other alternative method for obtaining unconfounded

Table 14. R^2-values for multiple regressions of yield on selected erosion control and other variables, MODELS II-34 to II-48

Model no.	Number of Obs.	Number of X variates	Variates deleted	R^2
II-34	622	51	YCPLANT2, YCPLANT2^2, and RANGE added to and MAN deleted from MODEL II-18	0.626
-36	622	49	YCPLANT2 and YCPLANT2^2 deleted from MODEL II-34	0.622
-37	622	49	YTERR and YTERR^2 deleted from MODEL II-34	0.621
-41	622	45	Linear and squared variates of YCPLANT1, YCPLANT2, and YTERR deleted from MODEL II-34	0.617
-42	543	47	All 79 terraced sites deleted from total observations; YCPLANT2 and YTERR (linear and squared terms) deleted from MODEL II-34	0.622
-43	543	45	YCPLANT1 and YCPLANT1^2 deleted from MODEL II-42	0.621
-44	350	49	All 272 contour planted only sites and YCPLANT2 and YCPLANT2^2 deleted from MODEL II-34	0.698
-45	350	47	YCPLANT1 and YCPLANT1^2 deleted from MODEL II-44	0.692
-47	350	45	YTERR and YTERR^2 deleted from MODEL II-45	0.677
-48	622	47	STK1A, DPMT, CRW^2, and STN^2 deleted from MODEL II-34	0.620

Table 15. Regression coefficients of erosion control variates, MODELS II-34 to II-48

Variate and associated b_i	Regression coefficients for designated variates						
	II-34	II-36	II-37	II-42	II-44	II-45	II-48
YCPLANT1 (b_1)	-2.044++	-0.107	0.575	-0.225	-2.459*	-	-2.157*
YCPLANT1^2 (b_{11})	0.068+	0.007	-0.033	-0.015	0.088*	-	0.075++
YCPLANT2 (b_2)	1.948++	-	-0.638	-	-	-	2.037++
YCPLANT2^2 (b_{22})	-0.059	-	0.041++	-	-	-	-0.064+
YTERR (b_3)	2.902**	0.796++	-	-	3.704**	1.446**	3.130**
YTERR^2 (b_{33})	-0.117**	-0.049*	-	-	-0.155**	-0.069**	-0.131**
Contour plant effect:							
Linear (b_1+b_2)	-0.096	-	-0.063	-0.225	-	-	-0.120
Quadratic ($b_{11}+b_{22}$)	0.009	-	0.008	0.015	-	-	0.010
Terrace effect:							
Linear (b_1+b_3)	0.858	0.689	-	-	1.245	1.446	0.973
Quadratic ($b_{11}+b_{33}$)	-0.049	-0.042	-	-	-0.067	-0.069	-0.056

effects of the erosion control variables was also tested. For this method, the data for the terraced and contoured only sites were deleted in alternative models to test the effects of contour planting and terracing, respectively, but with fewer observations (Table 14).

In MODELS II-42 and -43, all of the 79 observations from terraced sites were deleted to test the contour planting effect. The R^2 of 0.622 was about the same as that of MODEL II-34. The regression coefficients for the YCPLANT1 variates in MODEL II-42 were larger than the summed coefficients in MODEL II-34 (Table 15) but the effect of contouring gave very little increase in the R^2 (Table 14).

In MODELS II-44 to -47, 272 observations from sites that were contour planted only were deleted to investigate the terracing effect on yield (Table 14). The YCPLANT1 variates retained in the model had the same values as the YTERR variates except at the sites where the fields were contoured for some years prior to terracing. The summed coefficients in MODEL II-44 and the YTERR coefficients in MODEL II-45 were higher than those for the terrace effect in MODEL II-34 (Table 15). The R^2 values of MODELS II-44 and -45 were increased up to 2% by the addition of the YTERR variates.

The effects of years of contour planting and terracing on changes in corn yield (ΔY) as estimated from the different alternative models are given in Table 16. The changes in yields, using the summed coefficients listed in Table 15, were

Table 16. Change in yields, ΔY, as a function of years that erosion control practices were used, MODEL II series

Model no.	Contour plant or terrace effect	ΔY (bu/A) due to the following years				
		0	5	10	15	20
II-34	Contour plant	0	-0.2	-0.1	0.6	1.7
	Terrace	0	3.1	3.7	1.9	-2.4
-36	Terrace	0	2.4	2.7	0.9	-3.0
-37	Contour plant	0	-0.1	0.2	0.9	1.9
-42	Contour plant	0	-0.8	-0.8	0	1.5
-44	Terrace	0	4.6	5.8	3.6	-1.9
-45	Terrace	0	5.5	7.6	6.2	1.3

computed from the following relationships: ΔY for contour planting effect = $(b_1 + b_2) * \text{years} + (b_{11} + b_{22}) * \text{years}^2$ and ΔY for terracing effect = $(b_1 + b_3) * \text{years} + (b_{11} + b_{33}) * \text{years}^2$. Because no interactions were included in the model, the ΔY are average effects due to contour planting and terracing over all levels of the other variables in the quadratic model.

The yield responses (ΔY) due to years of contour planting were small but similar in all three models, with and without the terracing variates and with and without the observations from terraced sites (Table 16). The ΔY decreased slightly in the first few years and then increased to 1.5 to 1.9 bushels per acre after 20 years of contour planting.

The yield responses to years of terracing were larger than to contour planting and showed the same trend in all models by increasing up to 8 to 10 years after terracing and then decreasing (Table 16). The terracing effects with and without the YCPLANT2 variates (MODELS II-34 and -36, respectively) were similar. However, the yield responses to years of terracing estimated from MODELS II-44 and -45 (from which all contour planted only sites were deleted) were considerably larger than those estimated from Model II-34 using all observations.

The effects of contour planting and terracing in these quadratic models may be confounded with other factors because of the unequal distribution of the various erosion control practices in the different counties and on different soils as shown in Tables 17 and 18. Harrison County had the highest percentage of observations from terraced sites and Crawford County the lowest percentage. Cass and Woodbury counties had above average percentages of observations from sites only contour planted. Highest percentages of observations from noncontoured sites were in Adams and Crawford counties (Table 17).

Another possible source of confounding was that a higher percentage of the steeper soils and the lower productivity Ida and Dow soils were contour planted than the less sloping, more productive soils (Table 18). Also, a higher percentage of the till and paleosol soils (Shelby, Steinauer, Adair,

Table 17. Percentage of observations and average SLRATIO values from terraced, contour planted only, and noncontoured sites, all counties

County	No. of observations	Percentage of observations			Average SLRATIO[a]		
		Terraced	Contour planted	Noncontoured	Terraced	Contour planted	Noncontoured
Adams	89	13	32	55	13	17	55
Cass	158	10	54	36	13	14	51
Crawford	152	5	39	56	9	18	47
Harrison	87	37	30	33	11	14	46
Woodbury	136	8	54	38	14	12	67
All counties	622	12	44	44	11.7	14.4	53.3

[a] SLRATIO = (% slope of corn rows/% slope of site)*100.

Table 18. Percentage of observations from terraced, contour planted, and non-contoured sites on different slope and soil groups

			Percentage of observations		
Counties	Observation group	No. of observations	Terraced	Contour planted	Noncontoured
All	Slope: >10%	185	14	57	29
	1-10%	437	12	38	50
Adams, Cass, and Crawford	Till, paleosol soils	65	15	62	23
	Loess soils	334	8	40	52
Crawford, Harrison, and Woodbury	Ida and Dow soils	111	13	50	37
	Other loess soils	253	15	37	48

Clarinda, and Lamoni) were both terraced and contour planted than the loess soils.

In the quadratic model, the terracing and contour planting effects were compared at the average slope and pH of the plow layer because the SLOPE and PH1 variables were included in the final models. The till and paleosol variables were deleted because they were not significant at the 10% level. The effects on yield of these lower productivity soils (which had more terracing and contour planting than the loess soils) may be confounded some with the erosion control effects, although the DRAIN, EM3V, and PAWC variables may partially account for the effects of the till soils and paleosols on yield.

An underestimation of the erosion control effects may be due to the presence of the SLRATIO variable in the model because these effects are estimated at the average SLRATIO of all observations. In all counties the average SLRATIO values for terraced, contour planted only, and noncontoured observations were 12, 14, and 53, respectively (Table 17). Because the general effect of increasing SLRATIO (from on the contour to up-and-down hill) was negative, the response of contour planting or terracing at an average SLRATIO of 13 over noncontouring at its average SLRATIO of 53 would be larger than if compared at the average SLRATIO of 31.

Addition of interaction terms to the quadratic model should explain some of the erosion control effects better than the quadratic model does. For example, interactions of the contour planting and terracing variables with slope should give these effects on various slopes rather than at the average slope.

Model selection and effects of the variables on yield

Inclusion of all 98 variates in the first model (MODEL II-1) gave an R^2 of 0.82 (Table 10). Because the model selection in the absence of the BARR and SLKDATE variables was desired, deletion of these variables (4 variates) reduced the R^2 to 0.66. Deletion of variates in a series of models, addition of the YCPLANT2 variable, and deletion of a few more variates reduced the R^2 of the final model (MODEL II-48) to 0.62 (Table 14). The final model included 29 linear and 18 squared variates.

Some loss in R^2 was sacrificed by deleting nonsignificant variates in order to simplify the model. This loss indicated that many of these had slight, but not significant, effects on corn yield. Additional loss in R^2 occurred when some variables highly correlated with others were deleted. Some of these deleted variables were significant at the 5 to 10% level but were less significant than those retained. The highly correlated variables need not be deleted from a prediction model but probably should be deleted for a model to study relationships. Some of the correlated variables deleted from the final model of the MODEL II series will be included in the next series of regressions to select the most important interactions.

The regression coefficients and significances for each of the variates in the final MODEL II-48 are given in Table 19. Brief interpretations of the effects of the variables on yield are also given in Table 19; these will be discussed later.

Because no interaction variates were included, the effects of each variable on yield should be "independent" of the levels of the other variables. However, the effects of the variables on yield were at the average levels of the other variables and must be interpreted for the relevant or observed ranges of the other variables. The means and the ranges were given in Table 4. Also, varying degrees of correlation (Table 6 and Appendix Table A3) between many of the variables retained in the final model showed that the effects of these variables were not independent of the levels of the other variables. High correlations between variables may distort the regression coefficients so that the effect of a variable on yield may not appear to be very logical (Henao, 1976).

For the variables having quadratic functions in Table 19, the level of each variable associated with maximum yield (YMAX) or minimum yield (YMIN) was calculated. The partial derivative of yield with respect to the variable (dY/dX_i) was set equal to zero and then solved for X_i . This gives the

Table 19. Regression statistics of corn yield on selected variates in the final model, MODEL II-48

	Regression coefficients		
Variable	Linear	Squared	Interpretation
PLDEN	1.162**	-0.00330**	YMAX occurred at 176.1 or 17,610 stalks/A
RL3	-0.100**	-	Y decreased 0.1 bu/A for each 1% increase in root lodging
CRW	-0.383**	-	Y decreased 3.8 bu/A for each 10-unit rating of corn rootworm damage from 10= none to 50=severe
STLODG1	-0.257++	-	Y decreased 0.26 bu/A for each 1% increase in stalk breakage below ear
CB1	1.686**	-0.0860**	YMAX occurred at 9.8 cavities/10 stalks (moderate infestation)
CB2	0.323**	-0.00230+	YMAX occurred at 70 cavities/10 stalks (severe infestation)
WEEDS	-0.038**	-	Y decreased 0.38 bu/A for each increase of 100 lb/A weeds
CONTOUR PLANT (YEARS)	-0.120[a]	0.0103[a]	YMIN occurred at 5.8 years after contour planting
TERRACE (YEARS)	0.973[a]	-0.0561[a]	YMAX occurred at 8.7 years after terracing
PLDATE	0.708	-0.0162++	YMAX occurred at 21.9 or May 12
NFERT	0.156**	-0.00046	YMAX occurred at 171.2 lb/A of N
PFERT	0.320++	-0.00975*	YMAX occurred at 16.4 lb/A of P
KFERT	0.218*	-	Y increased 0.22 bu/A for each 1 lb/A of K

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[a] Coefficients of the erosion control variates are given in Table 15; no test of significance computed for the summed coefficients.

Table 19. (Continued)

Variable	Regression coefficients Linear	Squared
NCODE	-1.855**	0.0285**
PRES1	0.151*	-
SLOPE	-0.401++	-
SLRATIO	-0.170+	0.00145
PH1	7.625**	-0.0543**
STN	0.444**	-
STP1	1.074**	-0.0111**
RANGE	-0.644++	-
EROS	4.807*	-1.574++
DRAIN	-0.876	0.0111+

Interpretation
YMIN occurred at 32.5, between 3rd and 4th year corn
Y increased 0.15 bu for each 1 lb/A of P applied previous year
Y decreased 0.4 bu/A for each 1% increase in slope
YMIN occurred at a slope ratio of 59 (on the contour = 0 and up-and-down slope = 100)
YMAX occurred at 70.2 or pH of 7.0
Y increased 0.44 bu for each 1 pp2m increase in soil test N
YMAX occurred at 48 pp2m soil test P (high test)
Y decreased 0.64 bu/A for each unit from R32W to R47W
YMAX occurred at 1.5 or slight to moderate erosion
YMIN occurred at 40, moderately well-drained

Table 19. (Continued)

Variable	Regression coefficients Linear	 Squared	Interpretation
CPL	4.921**	-0.0967*	YMAX occurred at 25% clay in the plow layer
STP3	0.588**	-0.00815**	YMAX occurred at 36 pp2m soil test P in subsoil (medium)
EM3V	-1.307**	-	Y decreased 1.3 bu/A per unit increase in excess moisture index
DV	73.93**	-11.648**	YMAX occurred at 3.2, no moisture stress
PAWC	2.395*	-	Y increased by 2.4 bu/A for each inch increase in PAWC from 7 to 12 in./5 ft
Intercept	-449.2**		Large negative value because minimum values of several variables were much greater than zero

level of the variable associated with the zero slope of the quadratic yield function which is defined as YMAX or YMIN, depending on the signs of the coefficients of the linear and squared variates. If the coefficient of the linear term is positive and that of the squared term negative, the calculated level of X_i gives YMAX; if the signs are reversed, the level of X_i gives YMIN. If the signs of both coefficients are positive or negative, no YMAX or YMIN occurs in the positive rational range of the variable. For the variables having only linear functions, the effects of these on yield are linear relationships over the relevant ranges.

Most of the variables in MODEL II-48 had the expected effects on corn yield (Table 19) although the responses were not as high as expected because of the levels of other variables. For example, the average yield response (ΔY) to NFERT, shown in Figure 1A, was limited by mean PLDEN, NCODE, PFERT, and STP1 levels of 13,400 stalks/acre, 20 (2nd-year corn), 10.8 pounds of P (25 pounds P_2O_5) per acre, and 17 ppm soil test P (low part of low range), respectively.

The cumulative contour planting effect (Figure 1C) showed that yield decreased initially, reached a minimum after six years and then increased. The cumulative terracing effect (Figure 1D) showed that yield increased to a maximum after nine years and then decreased. The decreasing effect of years terraced after about 10 years cannot be explained readily. Very few of the older terraces were maintained at

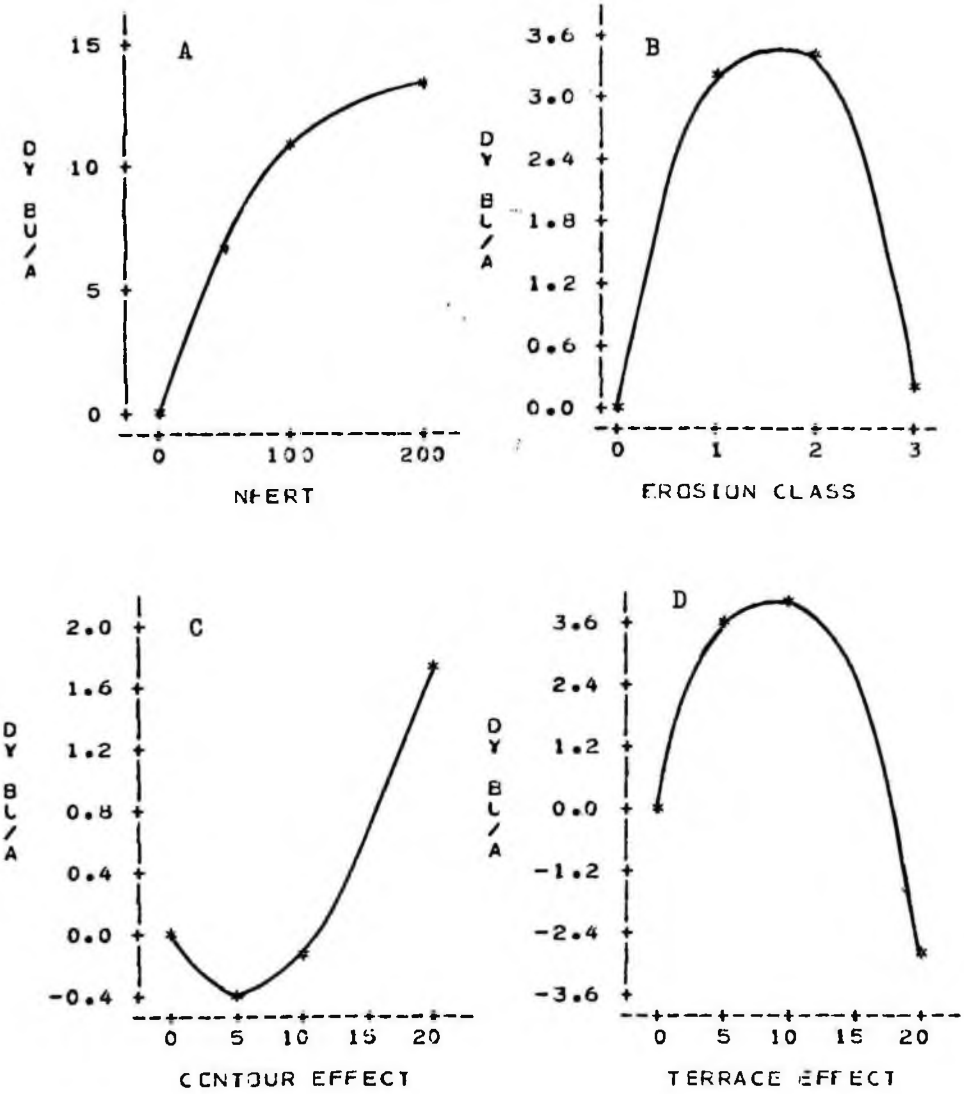

Figure 1. Changes in yield (DY or ΔY) due to (A) rates of N fertilizer (NFERT), (B) erosion class, (C) years contour planted (contour effect), and (D) years terraced (terrace effect) as computed from MODEL II-48

their original height and the oldest ones were silted in nearly to the top of the terrace. Also, this effect may be confounded with location and soils. Many of the oldest terraces were in Harrison County which had the highest percentage of terraced observations and the lowest mean yield of all counties (Appendix Table A2). Older terraces also occurred at the till and paleosol soil locations which had a higher percentage of terraced observations than loess soils in the area.

Increasing SLRATIO decreased yield initially to a minimum of 59 and then increased the yield (Table 19). The increasing yield beyond SLRATIO = 59 was unexpected but this effect may be confounded with slope. More of the high SLRATIO values occurred at the less sloping sites; as the slope increased, more farmers contoured or made an effort to avoid farming up-and-down hill by planting across the prevailing slope in the field. The maximum yield decrease computed from the regression coefficients of MODEL II-48 was 5.0 bushels per acre at SLRATIO = 59; at SLRATIO = 100, the decrease was 2.5 bushels per acre. The yield decrease from SLRATIO = 13 (about average for contoured and terraced observations) to SLRATIO = 53 (average for noncontoured sites) was 2.9 bushels per acre. Therefore, the yield responses of contour planting and terracing discussed in the previous paragraph will be about 2.9 bushels more positive if the average differences in SLRATIO associated with contouring or terracing are considered.

The corn yield responses to most of the variables including the highly significant weather indexes (Table 19) were in the expected direction and of generally the expected magnitude, considering the average levels of the other variables, and will not be discussed. Some that were not in the expected direction or magnitude will be discussed briefly.

Maximum corn yields occurred at medium and high infestation levels of CB1 and CB2, respectively. This irrational behavior of corn borer infestations on yield also was reported by Henao (1976). He indicated that the best corn probably attracted more egg-laying corn borer moths and that the confounding effects of high potential yields and high infestations were not separated by the mutliple regression.

The KFERT effect was small and positive. Because the mean KFERT rate was only 5.2 pounds of K per acre, the linear response indicated is relevant only for low rates of K fertilizer.

YMAX occurred at slight to moderate erosion (Table 19) but yield decreased markedly as erosion increased (Figure 1B). The lower yield of sites with no erosion (coded 0) than those with slight erosion was unexpected but the coefficients for the EROS variable may be distorted some because of its high correlation with SLOPE ($r = 0.62$).

The effect of DRAIN on yield, although not very significant, was different from that reported by Henao (1976) who found that YMAX occurred on moderately well-drained soils.

The high correlations between DRAIN and RANGE (r = -0.68) and PAWC (r = -0.52) may be distorting the DRAIN coefficients.

Most of the variates in the final model (MODEL II-48) were included in the next series of regressions in which the most significant interaction variates on yield were selected.

MODELS III, IV, and V Series: Selection of Interactions for Multiple Regressions of Corn Yield on Selected Variables

The purpose of this series of regression models was to select the most important interaction variates between the 29 linear management, erosion control, weather and soil variables to be included in the final model for predicting corn yields.

If all possible interactions were to be tested, 406 linear*linear interaction terms could be obtained from the 29 linear variables. From the total possible number of interactions, 131 were tested, basing the selection on research by Henao (1976) and also on *a priori* agronomic knowledge of which ones were likely to be the most important. All of the interactions could not be tested in a single model because the program used (Helarctos II) has a size limitation of 100 independent variables, including the dependent variate and one dummy variable. Along with the base set of 45 selected linear and squared variates (Table 20), 43, 44, and 44 interaction variates were tested in the MODEL III, IV, and V series (Table 21). The interactions were initially randomly selected for each of the models; then some were transferred

Table 20. Base set of linear and squared variates for testing interaction variates, MODEL III, IV, and V series

X_i	Variate	X_i	Variate	X_i	Variate
1	YIELD	17	SLOPE	32	CB1^2
2	PLDEN	18	SLRATIO	33	CB2^2
3	RL3	19	PH1	34	YCPLANT1^2
4	CRW	20	STN	35	YTERR^2
5	STLODG1	21	STP1	36	PLDATE^2
6	CB1	22	STK1A	37	N^2
7	CB2	23	EROS	38	P^2
8	WEEDS	24	DRAIN	39	K^2
9	YCPLANT1	25	CPL	40	NCODE^2
10	YTERR	26	DCAL	41	PH1^2
11	PLDATE	27	STP3	42	STP1^2
12	N	28	EM3V	43	EROS^2
13	P	29	DV	44	CPL^2
14	K	30	PAWC	45	STP3^2
15	NCODE	31	PLDEN^2	46	DV^2
16	PRES1				

from one model to another to obtain approximately the same number of interactions involving each variable in each of the three models.

For these interaction models, the MAN, NFERT, PFERT, and KFERT variables were replaced by the N, P, and K variables (the total N, P, and K applied in manure plus fertilizer). This was done to eliminate the many interactions involving the MAN variable with each of the fertilizer variables and with the same variables as any of the fertilizer variables. The effects of total applied nutrients were expected to be

Table 21. Interaction variates tested in MODELS III, IV, and V series

X_i	MODEL III	MODEL IV	MODEL V
47	PLDEN*CB1	PLDEN*CRW	PLDEN*WEEDS
48	*YCPLANT1	*YTERR	*N
49	*P	*PLDATE	*SLOPE
50	*NCODE	*EROS	*DV
51	CRW*P	RL3*N	RL3*CRW
52	CB1*NCODE	*NCODE	*DV
53	*DV	CRW*STP1	CRW*PLDATE
54	CB2*PLDATE	STLODG1*N	*N
55	WEEDS*N	CB1*N	*EROS
56	*EROS	*EROS	*DV
57	*DV	CB2*N	STLODG1*NCODE
58	YCPLANT1*N	*DV	CB1*CB2
59	*STP1	WEEDS*STN	*PLDATE
60	*EM3V	*EM3V	WEEDS*NCODE
61	YTERR*SLOPE	YCPLANT1*NCODE	YCPLANT1*P
62	*STN	*SLOPE	*EROS
63	*EROS	*SLRATIO	*DV
64	*DV	*STN	*PAWC
65	PLDATE*NCODE	YTERR*P	YTERR*N
66	*DV	*SLRATIO	*NCODE
67	N*P	*PAWC	*STP1
68	*STN	PLDATE*N	*EM3V
69	*SLOPE	*EM3V	PLDATE*P
70	*STP1	N*NCODE	N*EROS
71	*CPL	*PRES1	*EM3V
72	P*NCODE	P*PRES1	*DV
73	*EROS	*SLOPE	*PAWC
74	*DV	*PH1	P*CPL
75	K*EROS	*STP1	*STP3
76	*PAWC	K*NCODE	*PAWC
77	NCODE*SLOPE	*SLOPE	K*STK1A
78	*STN	NCODE*EROS	NCODE*PRES1
79	*STP1	*EM3V	*DCAL
80	PRES1*STP3	*DV	PRES1*EROS
81	Dummy	Dummy	Dummy
82	SLOPE*STP1	PRES1*STP1	SLOPE*SLRATIO
83	*DCAL	SLOPE*EROS	*STN
84	STP1*EROS	*PAWC	*STK1A
85	*DV	PH1*EROS	*DV

Table 21. (Continued)

X_i	MODEL III	MODEL IV	MODEL V
86	STK1A*EROS	STN*DV	SLRATIO*EROS
87	EROS*DCAL	STP1*DCAL	PH1*STP1
88	*STP3	STK1A*DV	*DCAL
89	EM3V*PAWC	EROS*DV	STN*EROS
90	DV*PAWC	DCAL*STP3	STP1*CPL
91	-	STP3*DV	*STP3

similar to those of the fertilizer nutrients because of the high correlations between N (total N) and NFERT (r = 0.91) and P and PFERT (r = 0.77).

The interactions with the YCPLANT2 variable, which was added after the initial regressions in all series had been run to get the unconfounded effects of contour planting, were not tested in the interaction series of models. The interactions with YCPLANT2 were added along with additional ones with YCPLANT1 and YTERR and tested in the final MODEL VII series. The addition of YCPLANT2 in the MODEL II series had little effect on the magnitudes or significances of the regression coefficients of the other variables. Omission of YCPLANT2 from these interaction models, therefore, would be expected to have little effect on the interactions involving the variables other than YCPLANT1 and YTERR.

The DCAL variable and its interaction variates were deleted after the initial model in each series because they showed little significance. The DCAL variable was also highly correlated with PH1 ($r = 0.79$) which had a highly significant curvilinear effect on yield in the MODEL II series.

Successive regressions were run in each of the series to select the most significant interactions. Only a few nonsignificant interactions were deleted in each of the successive steps because some interactions having low significance initially may become significant after those of lesser significance are deleted. Because 49 variates for the dependent, linear, and squared variates were needed for the MODEL VI series, the selection process was continued until 50 or fewer interaction terms remained in the three interaction models.

The R^2-values for the initial and final models in the MODELS III, IV, and V series are given in Table 22. The interactions selected from each series are listed in Table 23. Most of these were significant at the 1% to 10% levels. A few that were significant at the 15% and 20% level were retained for further testing.

MODEL VI Series: Initial Regressions of Corn Yield on Selected Linear, Squared, and Interaction Variates

The objective of the MODEL VI series was to combine all linear, squared, and interaction variates of the variables which had been selected in the previous series of models.

Table 22. R^2-values for selected multiple regressions of corn yield on selected variates, MODELS III, IV, and V series

Model no.	No. of variates	Description	No. of inter-actions	R^2
III-1	88	All variates listed in Tables 20 and 21	43	0.681
-11	61	27 variates deleted in successive models	17	0.663
IV-1	89	All variates listed in Tables 20 and 21	44	0.656
-9	57	32 variates deleted in successive models	13	0.643
V-1	89	All variates listed in Tables 20 and 21	44	0.662
-11	56	33 variates deleted in successive models	12	0.646

These models were run before the YCPLANT2 variable was added. Their main value is primarily to determine the importance of the interaction variates involving variables other than erosion control.

The BARR and SLKDATE variables have been found to be very sensitive indicators of yield. However, BARR and perhaps SLKDATE appear to be yield components and thus not good predictors of yield. In this series of models, therefore, two different sets of models were run, one with the BARR and SLKDATE variates and the other without them. Only the

Table 23. Interaction variates tested in the final regressions, MODELS III, IV, and V series

Model no.	Variate	t-value
III-11	PLDEN*YCPLANT1	-4.04**
	CRW*P	-3.17**
	WEEDS*N	-1.78++
	*DV	-2.92**
	YCPLANT1*N	1.71++
	*STP1	1.48+
	YTERR*STN	1.34
	*EROS	1.21
	N*P	2.24*
	P*NCODE	2.14*
	*DV	3.55**
	K*EROS	2.20*
	*PAWC	2.36*
	NCODE*STN	2.50*
	*STP1	-2.37*
	PRES1*STP3	-2.45*
	DV*PAWC	-2.70**
IV-9	PLDEN*YTERR	-2.70**
	*EROS	-1.62+
	CRW*STP1	-3.12**
	CB1*EROS	3.51**
IV-9	WEEDS*STN	-1.89++
	YCPLANT1*NCODE	2.37*
	*SLOPE	2.14*
	*STN	2.95**
	PLDATE*EM3V	1.55+
	N*NCODE	2.00*
	P*PH1	1.97*
	NCODE*DV	1.25
	PRES1*STP1	-1.35
V-11	PLDEN*N	1.65++
	*DV	4.53**
	RL3*DV	-2.21*
	CRW*PLDATE	-3.31**
	*DV	2.67**
	CB1*CB2	-1.63+
	*PLDATE	-1.88++
	YTERR*N	-1.34
	N*PAWC	1.34
	K*STK1A	-1.69++
	PRES1*EROS	2.60**
	PH1*STP1	-1.95*

quadratic functions of BARR and SLKDATE were included. The variates included in the MODEL VI series are listed in Table 24.

With BARR and SLKDATE variables

In the models including BARR and SLKDATE, MODELS VI-1 to VI-12, the nonsignificant variates were deleted in a series of steps retaining variates that were mostly significant at the 10% level. A linear variate was retained regardless of its significance as long as its squared term or one of its interactions was significant at the 10% level. The R^2-values of the initial and final models are given in Table 25. The R^2 of MODEL VI-1 was 0.827; addition of the interaction variates increased the R^2 very little compared to the quadratic model, MODEL II-1 ($R^2 = 0.819$).

The regression statistics of the final model after deleting 4 linear, 7 squared, and 33 interaction variates are given in Table 26. The final model included only 10 squared and 9 interaction variates other than those involving the erosion control variables. Five interactions were with the DV (moisture stress) variable. The YMIN occurred at 83% barren stalks and the negative linear effect of SLKDATE showed that yield was decreased about 0.7 bu per acre for each day delay in silking date.

The variables not involved in interactions showed the following effects: (1) CB1, CB2, PLDATE, PH1, CPL, and STP3

Table 24. Variates included in the preliminary models to select important interactions, MODEL VI series

X_i	Variate	X_i	Variate	X_i	Variate
1	YIELD	34	CB1^2	67	YCPLANT*N
2	PLDEN	35	CB2^2	68	*NCODE
3	BARR	36	YCPLANT1^2	69	*SLOPE
4	RL3	37	YTERR^2	70	*STN
5	CRW	38	PLDATE^2	71	*STP1
6	STLODG1	39	SLKDATE^2	72	YTERR*N
7	CB1	40	N^2	73	*STN
8	CB2	41	P^2	74	*EROS
9	WEEDS	42	K^2	75	PLDATE*EM3V
10	YCPLANT1	43	NCODE^2	76	N*P
11	YTERR	44	PH1^2	77	*NCODE
12	PLDATE	45	STP1^2	78	*STN
13	SLKDATE	46	EROS^2	79	*DV
14	N	47	CPL^2	80	*PAWC
15	P	48	STP3^2	81	P*NCODE
16	K	49	DV^2	82	Dummy
17	NCODE	50	PLDEN*YCPLANT	83	P*PH1
18	PRES1	51	*YTERR	84	*STP1
19	SLOPE	52	*N	85	*DV
20	SLRATIO	53	*EROS	86	K*STK1A
21	PH1	54	*DV	87	*EROS
22	STN	55	RL3*DV	88	*PAWC
23	STP1	56	CRW*PLDATE	89	NCODE*STN
24	STK1A	57	*P	90	*STP1
25	EROS	58	*STP1	91	*DV
26	DRAIN	59	*DV	92	PRES1*STP1
27	CPL	60	CB1*CB2	93	*EROS
28	STP3	61	*PLDATE	94	*STP3
29	EM3V	62	*EROS	95	PH1*STP1
30	DV	63	*DV	96	*EROS
31	PAWC	64	WEEDS*N	97	STP1*DV
32	PLDEN^2	65	*STN	98	DV*PAWC
33	BARR^2	66	*DV		

Table 25. R^2-values for selected multiple regressions, MODEL VI series

Model no.	No. of X_i	Description	R^2
VI-1	96	All variates including BARR and SLKDATE	0.827
-12	52	4 linear, 7 squared and 33 interaction terms deleted stepwise from MODEL VI-1	0.817
-20	92	All variates included except BARR and SLKDATE	0.700
-65	61	8 linear, 4 squared and 22 interaction terms deleted stepwise from MODEL VI-20	0.687

produced increasing yields at a decreasing rate up to a YMAX and then decreased yields; (2) PRES1 gave a linear yield increase; and (3) STLODG1 and EM3V gave linear yield decreases.

Most of the significant interactions in MODEL VI-12 also occurred in the next series of models and these will be discussed later. Four were significant in MODEL VI-12 and not in the next series of models (Table 26). The negative CRW*STP1 interaction, also observed by Henao (1976), showed that the negative effect of CRW on yield became larger as the STP1 level increased. The positive N*NCODE interaction showed that the response to N increased as NCODE increased or as the position of corn in the rotation changed from first-year corn to continuous corn. The negative response to

Table 26. Regression statistics for the final models used to select interaction variates, MODELS VI-12 and VI-65

	Regression coefficients (b_i)	
Variate	MODEL VI-12	MODEL VI-65
PLDEN	0.545**	0.560*
RL3	-	0.565*
BARR	-2.234**	-
CRW	-0.799++	-0.659
STLODG1	-0.233*	-0.220++
CB1	0.658**	2.361**
CB2	0.267**	0.328**
WEEDS	0.0944++	0.188*
YCPLANT1	-0.802**	-0.120
YTERR	-1.299	0.538
PLDATE	0.834*	2.057**
SLKDATE	-0.746**	-
N	0.0330	-0.0329
P	-0.618*	-2.148**
K	-0.377**	-
NCODE	-1.668**	-3.340**
PRES1	0.0941++	0.410**
SLOPE	0.112	-
PH1	3.104*	12.725**
STN	0.227**	0.203
STP1	0.630*	3.171**
EROS	-1.303++	6.228+
CPL	4.712**	5.101*
STP3	0.286*	0.268**
EM3V	-0.642*	-3.660**
DV	-17.69*	19.51
PAWC	0.432	11.07*
PLDEN^2	-0.0017**	-0.0032**
BARR^2	0.0135**	-
CB1^2	-0.0333**	-0.0901**
CB2^2	-0.0027**	-0.0032*
YCPLANT1^2	-	0.0196+
YTERR^2	0.618**	-
PLDATE^2	-0.0123++	-0.0251**
N^2	-	-0.0011**
P^2	-	-0.0095*
NCODE^2	0.0244**	0.0418**
PH1^2	-0.0221++	-0.0915**
STP1^2	-0.0082**	-0.0155**
EROS^2	-	-1.253+
CPL^2	-0.0873**	-0.0949*
STP3^2	-0.0035++	-

Table 26. (Continued)

	Regression coefficients (b_i)	
Variate	MODEL VI-12	MODEL VI-65
PLDEN*YCPLANT1	-	-0.0053+
*YTERR	-0.0197**	-0.0170**
*N	-	0.0016*
*EROS	-	-0.0414++
*DV	0.121*	0.241**
RL3*DV	-	-0.256*
CRW*PLDATE	-	-0.0460**
*P	-	-0.0266**
*STP1	-0.0122*	-
*DV	0.375*	0.753**
CB1*PLDATE	-	-0.0541++
*EROS	-	0.374*
WEEDS*STN	-	-0.0011+
*DV	-0.0494*	-0.0634*
YCPLANT1*NCODE	0.0162**	-
*SLOPE	0.0259+	-
*STP1	0.0089*	0.0172**
YTERR*STN	0.0459**	0.0293*
*EROS	0.271*	0.230+
PLDATE*EM3V	-	0.0778++
N*P	-	0.0044*
*NCODE	0.0032**	-
P*NCODE	-	0.0218**
*PH1	-	0.0228**
*DV	0.272**	0.287*
K*PAWC	0.0318*	-
NCODE*STN	-	0.0151*
*STP1	-0.0055+	-0.0109*
PRES1*STP3	-	-0.0165**
PH1*STP1	-	-0.0274**
STP1*DV	0.166++	-
DV*PAWC	-	-4.107++
Intercept	-107.41*	-604.81**
R^2	0.817	0.687

K (total K) decreased as the PAWC increased (positive K*PAWC interaction); this effect cannot be readily explained because the lowest soil test K levels occurred in the till and paleosol soils having the lowest PAWC and in some of the Ida and Monona soils having the highest PAWC. The response to STP1 level increased as DV values increased (moisture stress decreased) as shown by the positive STP1*DV interaction; this is the expected effect (Henao, 1976).

Without BARR and SLKDATE variables

In MODELS VI-20 to VI-65 (not inclusive), the BARR and SLKDATE variables were deleted and the nonsignificant variables were deleted in a series of steps. The R^2-values of the initial and final models are given in Table 25. The regression statistics of the final model, MODEL VI-65, are given in Table 26. Variates retained in the final model were 23 linear, 12 squared, and 26 interaction variates. Addition of the interaction variates gave an R^2 of 0.687 (MODEL VI-65, Table 25) compared to 0.623 for the quadratic model (MODEL II-18, Table 10).

Excluding the erosion control variates, MODEL VI-65 had 2 more significant squared variates, 12 more interaction variates, but 1 less linear variate than MODEL VI-12 (Table 26). The BARR (primarily) and SLKDATE variables were accounting for many of the interaction effects among other variables on corn yields.

The effects of most variables were similar in the two models although more curvilinear and interaction effects occurred in MODEL VI-65. The direction and magnitudes of the variable effects on yields cannot be estimated by a casual inspection of the coefficients of the linear variates in an interaction model. For example, the slopes of the DV linear variate in the two models appeared to be much different. But the slopes of DV calculated from the partial derivatives of yield on DV at the mean levels of the interacting variables were about 10 and 16 for MODELS VI-12 and VI-65, respectively.

Most of the interaction effects on yield in MODEL VI-65 were in the expected direction (Table 26) and similar to those reported by Henao (1976). Only the interactions involving the soil and management variables will be discussed. The initial positive yield response to increasing plant density was increased by higher levels of N and DV (less moisture stress) because of the positive interactions and was decreased as erosion class increased (negative interaction). The positive PLDATE*EM3V interaction showed that the adverse effect of excess moisture became less as planting date was delayed.

The positive interactions involving total P applied (Table 26) showed that the response to P increased as N rates increased, as NCODE changed from first-year to continuous corn, as soil pH increased, and as moisture stress decreased. The negative response to NCODE became less as the STN level increased because of the positive NCODE*STN interaction and increased as the STP1 level increased (negative NCODE*STP1 interaction). The negative PRES1*STP3 interaction showed that the yield increase to residual P became less as subsoil P level increased. The positive response to increasing levels of STP1 became less as the soil pH of the plow layer increased (negative PH1*STP1 interaction). Finally, the negative DV*PAWC interaction showed that positive response to increasing plant available water capacity became less as moisture stress decreased.

All of these interactions show the complex relationships between yield and the many variables affecting yield. The interactions involving some of the environmental variables, although of little interest in this study, do explain some of the yield variation. Thus, they increase the R^2 (decrease the error variance) which gives more precision in determining the effects of the variables of interest.

MODEL VII Series: Final Multiple Regressions of Corn Yield on Selected Variates

In this series of corn yield regressions, the YCPLANT2 erosion control variable was added along with 14 additional interaction terms with YCPLANT1, YCPLANT2, and YTERR. All the linear and squared terms selected in the final models of the MODEL VI series were retained except the CRW*STP1, K*PAWC, and STP1*DV variates. These interactions had shown some significance in MODEL VI-12 but little significance in the model series without BARR and SLKDATE, MODEL VI-65. Five interactions were added for retesting; these were PLDEN*P. N*DV, P*STP1, K*STK1A, and SLOPE*SLRATIO. The variates initially included in the MODEL VII series are listed in Table 27.

Models utilizing all data (622 observations) were run with and without the BARR and SLKDATE variables but only the results of the series without the BARR and SLKDATE variables will be discussed. In the initial models for both sets, combinations of the three erosion control variables and their interactions were tested.

Additional models were run by alternatively deleting the 79 terraced observations and the 272 contour planted observations. These were run to compare the effects of years contour planted and terraced with their effects estimated in the models containing all observations. This same testing procedure was also used in the final stages of the MODEL II series. In the final stage of model selection, the nonsignificant variates were deleted stepwise from the model including all observations and without the BARR and SLKDATE variables.

<u>MODELS VII-17 to VII-25</u>

These models were used to study the effects of the erosion control variables and their interactions on yield. The descriptions and R^2-values for the regressions are presented in Table 28. Nonsignificant variates were not deleted so all the variates listed in Table 27 were included, except as noted

Table 27. Variates included in the final regression models, MODEL VII series

X_i	Variate	X_i	Variate	X_i	Variate
1	YIELD	35	CB1^{2}	68	YCPLANT1*SLOPE
2	PLDEN	36	CB2^{2}	69	*SLRATIO
3	BARR	37	YCPLANT1^{2}	70	*STN
4	RL3	38	YCPLANT2^{2}	71	*STP1
5	CRW	39	YTERR^{2}	72	*EROS
6	STLODG1	40	PLDATE^{2}	73	YCPLANT2*NCODE
7	CB1	41	SLKDATE^{2}	74	*SLOPE
8	CB2	42	N^{2}	75	*SLRATIO
9	WEEDS	43	P^{2}	76	*STN
10	YCPLANT1	44	K^{2}	77	*STP1
11	YCPLANT2	45	NCODE^{2}	78	*EROS
12	YTERR	46	PH1^{2}	79	YTERR*NCODE
13	PLDATE	47	STP1^{2}	80	*SLOPE
14	SLKDATE	48	EROS^{2}	81	*SLRATIO
15	N	49	CPL^{2}	82	*STN
16	P	50	STP3^{2}	83	Dummy
17	K	51	DV^{2}	84	YTERR*STP1
18	NCODE	52	PLDEN*YCPLANT1	85	*EROS
19	PRES1	53	*YCPLANT2	86	PLDATE*EM3V
20	SLOPE	54	*YTERR	87	N*P
21	SLRATIO	55	*N	88	*NCODE
22	PH1	56	*P	89	*DV
23	STN	57	*EROS	90	P*NCODE
24	STP1	58	*DV	91	*PH1
25	STK1A	59	RL3*DV	92	*STP1
26	EROS	60	CRW*PLDATE	93	*DV
27	DRAIN	61	*P	94	K*STK1A
28	CPL	62	*DV	95	NCODE*STN
29	STP3	63	CB1*PLDATE	96	*STP1
30	EM3V	64	*EROS	97	PRES1*STP3
31	DV	65	WEEDS*STN	98	SLOPE*SLRATIO
32	PAWC	66	*DV	99	PH1*STP1
33	PLDEN^{2}	67	YCPLANT1*NCODE	100	DV*PAWC
34	BARR^{2}				

Table 28. R^2-values for regressions of corn yield on various combinations of erosion control variables and numbers of observations, without BARR and SLKDATE variables, MODELS VII-17 to VII-25

Model no.	No. of obs.	No. of X_i	Description	R^2
VII-22	622	94	All observations, all variates; tested YCPLANT1, YCPLANT2, and YTERR	0.709
-23	622	85	YCPLANT2 variates deleted; tested YCPLANT1 and YTERR	0.699
-24	622	85	YTERR variates deleted; tested YCPLANT1 and YCPLANT2	0.695
-17	622	67	YCPLANT1, YCPLANT2, and YTERR variates deleted	0.668
-18	543	76	Deleted 79 terraced observations; tested only YCPLANT1	0.695
-19	543	67	YCPLANT1 variates deleted	0.688
-25	350	85	Deleted 272 contour planted observations; tested YCPLANT1 and YTERR	0.766
-20	350	76	YCPLANT1 variates deleted; tested YTERR	0.751
-21	350	67	YCPLANT1 and YTERR variates tested	0.707

in Table 28. MODEL VII-22 in which all variates were included and from which both the contour planted and terraced effects can be determined gave an R^2 of 0.709. When all 27 erosion control variates were deleted in MODEL VII-17, an R^2 of 0.668 was obtained. These erosion control variates therefore accounted for 4.1% of the variation in corn yields.

The effect of years terraced on corn yield, disregarding the effect of YCPLANT2, was tested in MODEL VII-23 by deleting all YCPLANT2 variates and then summing the coefficients of all YCPLANT1 and YTERR variates. Similarly, the effect of years contour planted on yields was tested by deleting all YTERR variates in MODEL VII-24 and summing the regression coefficients of all YCPLANT1 and YCPLANT2 variates. The individual coefficients for all YCPLANT1, YCPLANT2, and YTERR variates in MODELS VII-22 to VII-24 and their significance levels are given in Table 29. The summed regression coefficients to give the effects of years contour planted (designated YRS-CP to differentiate the summed effect of two regression coefficients from the coefficients of the original variates) and years terraced (designated YRS-TERR) are given in Table 30.

The effect of YRS-CP was further tested in an alternative model by deleting all 79 terraced observations (MODEL VII-18, Table 28). In this model, the YCPLANT1 variates gave only a small increase in R^2 compared to MODEL VII-19 from which the YCPLANT1 variates were deleted. The R^2 of MODEL VII-18 was the same as that for MODEL VII-24 in which the contour planted effect was determined from all observations. The regression coefficients for the YCPLANT1 variates are given in Table 30.

The effect of YRS-TERR was tested in another alternative model in which 272 contour planted only observations were deleted (Table 28). In one of the models (VII-25), both

Table 29. Regression coefficients for all YCPLANT1, YCPLANT2, and YTERR variates, without BARR and SLKDATE variables, MODEL VII series

	b_i-values for variates in following models			
Variate[a]	VII-22	VII-23	VII-24	VII-25
1	-7.9845*	-0.5287	1.2984	-8.3910*
2	7.4470++	-	-1.7588	-
3	10.2201*	2.1763	-	9.4356*
1^2	0.1168++	-0.0009	-0.0394+	0.1113+
2^2	-0.1178++	-	0.0375	-
3^2	-0.1615**	-0.0377	-	-0.1334++
PLDEN*1	0.0333*	-0.0049	-0.0191**	0.0361*
*2	-0.0393**	-	0.0126*	-
*3	-0.0567**	-0.0184**	-	-0.0631**
NCODE*1	-0.1682*	0.0040	0.0224++	-0.1672*
*2	0.1734*	-	-0.0186	-
*3	0.2015*	0.0202	-	0.2005*
SLOPE*1	0.3461*	0.0224	-0.0635	0.3823*
*2	-0.3293++	-	0.0941*	-
*3	-0.6204**	-0.2148*	-	-0.5586*
SLRATIO*1	0.0430	0.0076	-0.0256	0.0543
*2	-0.0335	-	0.0350++	-
*3	-0.0863	-0.0530*	-	-0.0833
STN*1	-0.0073	0.0123	0.0300*	-0.0109
*2	0.0217	-	-0.0156	-
*3	0.0485	0.0295	-	0.0611++
STP1*1	0.0220	0.0100+	0.0237*	0.0200
*2	-0.0136	-	-0.0164+	-
*3	-0.0149	0.0159	-	-0.0032
EROS*1	-0.9944*	-0.1065	0.1152	-1.0450*
*2	0.9625*	-	-0.1825	-
*3	1.8262**	0.6365*	-	1.7114**

[a] To simplify listing of variates, 1 = YCPLANT1, 2 = YCPLANT2, and 3 = YTERR.

Table 30. Regression coefficients for the effects of years contour planted and terraced on corn yields, without BARR and SLKDATE variables, MODEL VII series

Variates	VII-22 (n=622)	VII-23 (n=622)	VII-24 (n=622)	VII-18 (n=543)	VII-25 (n=350)	VII-20 (n=350)
	b_i-values for variates in following models					
	Contour planted effect[a]					
YRS-CP	-0.5375		-0.4604	-0.5636		
YRS-CP^2	-0.0010		-0.0019	-0.0005		
YRS-CP*PLDEN	-0.0060		-0.0065	-0.0057^{+}		
*NCODE	0.0052		0.0038	0.0038		
*SLOPE	0.0168		0.0306	0.0109		
*SLRATIO	0.0095		0.0094	0.0105		
*STN	0.0144		0.0144	0.0141		
*STP1	0.0084		0.0073	0.0090		
*EROS	-0.0319		-0.0673	-0.0069		

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[a] YRS-CP = effect of years contour planted and $b_i = \Sigma b_i$ of YCPLANT1 and YCPLANT2 variates listed in Table 29 for MODELS VII-22 and VII-24. Only the YCPLANT1 variates were tested in MODEL VII-18 and significance of each is shown in this table.

Table 30. (Continued)

Variates	b_i-values for variates in following models					
	VII-22 (n=622)	VII-23 (n=622)	VII-24 (n=622)	VII-18 (n=543)	VII-25 (n=350)	VII-20 (n=350)
			Terraced effect[b]			
YRS-TERR	2.2356	1.6476			1.0446	0.2347
YRS-TERR^2	-0.0447	-0.0386			-0.0221	-0.0068
YRS-TERR*PLDEN	-0.0234	-0.0233			-0.0270	-0.0292**
*NCODE	0.0333	0.0242			0.0333	0.0230
*SLOPE	-0.2743	-0.1924			-0.1763	-0.0396
*SLRATIO	-0.0433	-0.0454			-0.0290	-0.0310
*STN	0.0412	0.0418			0.0502	0.0535**
*STP1	0.0071	0.0259			0.0168	0.0347++
*EROS	0.8318	0.5300			0.6664	0.3345

[b] YRS-TERR = effect of years terraced and $b_i = \Sigma b_i$ of YCPLANT1 and YTERR variates listed in Table 29 for MODELS VII-22, -23, and -25. Only the YTERR variates were tested in MODEL VII-20 and significance of each is shown in this table.

the YCPLANT1 and YTERR variates were included. The YCPLANT1 value was different from the YTERR value only if the field had been contour planted before it was terraced; consequently, both variables were highly correlated ($r = 0.88$). The R^2 value of 0.766 was higher than that for MODEL VII-22 which was based on all observations. Deletion of the YCPLANT1 variates in MODEL VII-20 decreased the R^2 to 0.751 and deletion of the YTERR variates in MODEL VII-21 decreased the R^2 considerably to 0.707. The regression coefficients for the erosion control variates in MODEL VII-25 are given in Table 29 and the summed coefficients for MODEL VII-25 and the coefficients for MODEL VII-20 are given in Table 30.

The summed regression coefficients for YRS-CP in MODELS VII-22 and -24 and those in MODEL VII-18 had the same signs and were very similar for all variates except YRS-CP*SLOPE and YRS-CP*EROS (Table 30). The coefficients for YRS-YTERR also had the same signs but were more variable among models; those in MODEL VII-20 deviated the most from the other models (Table 30). Although MODELS VII-20 and -25 were derived from the same data set (350 observations), deletion of the YCPLANT1 variable highly correlated with YTERR markedly changed the coefficients of 5 of the 9 variates. Presence of two highly correlated variables ($r = 0.88$) in the same model often causes distortion of the regression coefficients (Henao, 1976).

The estimated effects of YRS-CP and YRS-TERR on corn yields from the different models were investigated using the regression coefficients in Table 30. This is illustrated by setting all interacting variables at fixed levels and computing a simplified equation for change in yield (ΔY). PLDEN was set at 150 (15,000 stalks/acre), NCODE at 30 (third-year corn), SLOPE at 8%, SLRATIO at 30, STN at 65 pp2m, STP1 at 25 pp2m, and EROS at 2. The simplified equations for change in yield (ΔY) as functions of YRS-CP and YRS-TERR at fixed levels of the interacting variables were:

$$\Delta Y = b_i * \text{YRS-CP} + b_{ii} * \text{YRS-CP}^2 \quad \text{and} \tag{6}$$

$$\Delta Y = b_i * \text{YRS-TERR} + b_{ii} * \text{YRS-TERR}^2 \quad , \tag{7}$$

where b_i = the sum of the coefficient for the linear variate plus the products of the b_i's and each of the respective fixed levels of the interacting variables in the interaction variates and b_{ii} = the coefficient of the squared variate.

The computed coefficients for simplified equations 6 and 7, the changes in yield computed from these equations for 0, 10, and 20 years contour planted and terraced, and the number of years associated with maximum yield (YMAX) are given in Table 31 and illustrated in Figure 2.

The effect of YRS-CP was nearly a linear response in all models with yield responses being more similar in MODEL VII-22 (all observations, all 3 erosion control variates) and MODEL VII-18 (79 terraced observations deleted). YRS-TERR, however, presented different yield response patterns in the two alternative data sets in which all 622 observations occurred and

Table 31. Effects of years of contouring and terracing on yield at selected levels of interacting variables, MODEL VII series[a]

	MODELS					
	VII-22	VII-23	VII-24	VII-18	VII-25	VII-20
Contour planted effect						
b_i YRS-CP	0.2201		0.1893	0.2253		
b_{ii} YRS-CP^2	-0.0010		-0.0019	-0.0005		
ΔY at YRS-CP=0	0		0	0		
=10	2.1		1.7	2.2		
=20	4.0		3.0	4.3		
YRS-CP at YMAX	110		50	225		
Terrace effect						
b_i YRS-TERR	0.7503	0.4019			0.7290	0.2939
b_{ii} YRS-TERR^2	-0.0447	-0.0386			-0.0221	-0.0068
ΔY at YRS-TERR=0	0	0			0	0
=10	3.0	0.1			5.1	2.2
=20	-2.9	-7.4			5.8	3.2
YRS-TERR at YMAX	8.4	5.2			16.5	21.6

[a] Simplified ΔY equations computed from regressions given in Table 30 at PLDEN = 150, NCODE = 30, SLOPE = 8, SLRATIO = 30, STN = 65, STP1 = 25, and EROS = 2.

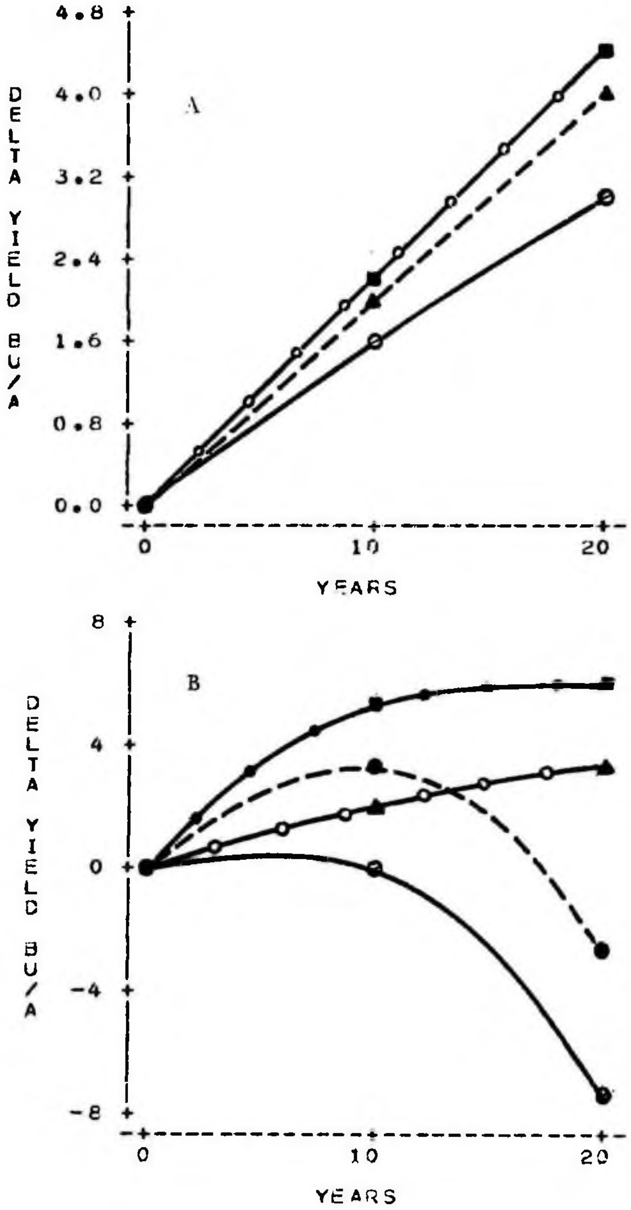

Figure 2. Changes in yield (DELTA YIELD or ΔY) due to (A) years contour planted and (B) years terraced as computed from the various models shown in Table 31

in which 272 contour planted observations were deleted (Table 31). In the former models, MODELS VII-22 and VII-23, yield response increased in the initial years terraced, reached a YMAX in 5 to 8 years, and then decreased to negative values. This trend was also observed in the MODEL II series. However, deletion of the contour planted sites, MODELS VII-20 and -25, gave a pattern in which yields increased to YMAX in 17 to 22 years.

These inconsistencies may show possible confounding within the data due to unequal distribution of the various erosion control practices in the five counties and on soils of different productivity levels.

Setting the levels of the interacting variables at other levels will change the ΔY and the years associated with YMAX. The signs of the interactions show the effects of these variables on the contour planted and terraced yield effects (Table 30). The response to YRS-CP will be decreased as plant density and erosion class increase and will be increased as NCODE, SLOPE, SLRATIO, STN, and STP1 levels increase. Response to YRS-TERR will be decreased as PLDEN, SLOPE, and SLRATIO increase and increased as NCODE, STN, STP1, and EROS increase. Three of the interactions, those with SLOPE, SLRATIO, and EROS, had different signs in the years contour planted and years terraced models.

MODELS VII-41 to VII-43

The final model utilizing all observations after deleting the nonsignificant variates from MODEL VII-22 by a series of backward selections was MODEL VII-41. The R^2 is given in Table 32 and the regression statistics are given in Table 33. All of the squared and interaction variates retained were significant at the 10% to 1% levels. A linear variate was retained as long as its squared term or one of its interactions was significant at the 10% level. The three interactions between any variable and the three erosion control variables were deleted or retained as a unit.

The coefficients for YRS-CP and YRS-TERR were computed by summing the two appropriate coefficients for each of the linear, squared and interaction variates given in Table 33. These summed coefficients are given in Table 34.

The effect of YRS-CP on yield was essentially linear because the coefficient of the squared term was almost zero (Table 34). The interactions involving YRS-CP showed that the initial positive response to years contour planted decreased as levels of PLDEN, SLOPE, and EROS increased but increased as NCODE increased (changed from first year to continuous corn).

The YRS-TERR had a curvilinear effect on yield, generally increasing the yield to a maximum and then decreasing with increasing number of years terraced. This effect was noted previously for the models using all observations. At

Table 32. R^2-values for final regressions of corn yield on selected variates for combinations of the SLOPE and EROS variables and different numbers of observations, MODELS VII-41 to VII-46

Model no.	No. of obs.	No. of X_i	Description	R^2
VII-41	622	69	Nonsignificant variates deleted stepwise from MODEL VII-22	0.691
-42	622	63	6 EROS variates deleted from MODEL VII-41 to test SLOPE variates	0.675
-43	622	65	4 SLOPE variates deleted from MODEL VII-41 to test EROS variates	0.684
-44	350	54	Nonsignificant variates deleted stepwise from MODEL VII-25	0.746
-45	350	51	3 EROS variates deleted from MODEL VII-44 to test SLOPE variates	0.735
-46	350	51	3 SLOPE variates deleted from MODEL VII-44 to test EROS variates	0.738

some levels of the interacting variables, the yield decreased initially with years and then decreased at an increasing rate, as will be shown later. The interactions involving YRS-TERR showed that the initial positive response decreased as PLDEN and SLOPE increased and increased as NCODE and EROS increased (Table 34).

The effects of different levels of the interacting variables on the cumulative yield response (ΔY) to YRS-CP and

Table 33. Regression statistics for the final models of corn yield on selected variates, MODELS VII-41 to VII-43 (n=622)

	b_i-values for variates in following models		
Variate	VII-41	VII-42	VII-43
PLDEN	0.637*	0.636*	0.580*
RL3	0.592*	0.667*	0.635*
CRW	-0.883	-1.030+	-1.024+
STLODG1	-0.264*	-0.246++	-0.240++
CB1	2.607**	2.953**	2.608**
CB2	0.112**	0.120**	0.106**
WEEDS	0.147*	0.162*	0.145*
YCPLANT1	-9.8130**	-8.1699**	-2.9906++
YCPLANT2	10.7766**	9.0456**	3.9113*
YTERR	13.3159**	11.2233**	5.3440**
PLDATE	1.794**	1.680**	1.726**
N	-0.105	-0.0882	-0.113
P	-0.541	-0.665	-0.584
NCODE	-3.043**	-3.091**	-3.052**
PRES1	0.442**	0.400**	0.435**
SLOPE	-0.0578	0.0259	-
PH1	10.959**	11.499**	11.785**
STN	0.218++	0.306*	0.266*
STP1	3.034**	2.832**	2.987**
EROS	1.778	-	1.760
CPL	4.865*	6.319**	4.639*
STP3	0.349**	0.278**	0.322**
EM3V	-4.599**	-4.237**	-4.514**
DV	63.43++	50.09+	52.12+
PAWC	11.860*	12.113*	10.931*
PLDEN^2	-0.0034**	-0.0037**	-0.0034**
CB1^2	-0.0914**	-0.0858**	-0.0908**
YCPLANT1^2	0.2031**	0.1872**	0.1076*
YCPLANT2^2	-0.2032**	-0.1903**	-0.1066*
YTERR^2	-0.2325**	-0.2160**	-0.1026*
PLDATE^2	-0.0224*	-0.0217*	-0.0215*
N^2	-0.0013**	-0.0013**	-0.0013**
P^2	-0.0084*	-0.0083++	-0.0076++

Table 33. (Continued)

Variate	b_i-values for variates in following models		
	VII-41	VII-42	VII-43
NCODE^2	0.0354**	0.0379**	0.0384**
PH1^2	-0.0780**	-0.0831**	-0.0845**
STP1^2	-0.0145**	-0.0145**	-0.0143**
EROS^2	-1.3963++	-	-1.4082++
CPL^2	-0.0939*	-0.1188**	-0.0896*
DV^2	-6.497++	-4.982+	-5.965++
PLDEN*YCPLANT1	0.0385**	0.0247*	0.0135+
*YCPLANT2	-0.0459**	-0.0312**	-0.0211*
*YTERR	-0.0589**	-0.0474**	-0.0364**
PLDEN*N	0.0024**	0.0023**	0.0025**
*P	-0.0049++	-0.0037	-0.0045++
*DV	0.2326**	0.2567**	0.2471**
RL3*DV	-0.2684**	-0.2916**	-0.2804**
CRW*PLDATE	-0.0410**	-0.0371**	-0.0402**
*P	-0.0254**	-0.0259**	-0.0247**
*DV	0.7941**	0.8149**	0.8329**
CB1*PLDATE	-0.0574*	-0.0596**	0.588*
*EROS	0.3387*	-	0.3386*
WEEDS*DV	-0.0749**	-0.0809**	-0.0747**
YCPLANT1*NCODE	-0.2045**	-0.0925+	-0.0511
*SLOPE	0.3376**	0.1253	-
*EROS	-0.8941**	-	-0.5871*
YCPLANT2*NCODE	0.2179**	0.1044+	0.0643
*SLOPE	-0.3419**	-0.1405	-
*EROS	0.8123**	-	0.5137*
YTERR*NCODE	0.2346**	0.1227++	0.0675
*SLOPE	-0.6104**	-0.1624	-
*EROS	1.7381**	-	0.8702**

Table 33. (Continued)

	b_i-values for variates in following models		
Variate	VII-41	VII-42	VII-43
PLDATE*EM3V	0.1050*	0.0941*	0.1028*
N*P	0.0053**	0.0049**	0.0051**
P*NCODE	0.0171**	0.0186**	0.0162**
*PH1	0.0183**	0.0175*	0.0179**
NCODE*STN	0.0097^{++}	0.0083	0.0080
PRES1*STP3	-0.0191**	-0.0175**	-0.0182**
PH1*STP1	-0.0276**	-0.0244*	-0.0271**
DV*PAWC	-4.7426*	-4.4549*	-4.1946*
Intercept	-599.93***	-626.78**	-601.43**

Table 34. Summed regression coefficients for the effects of years contour planted and terraced, MODELS VII-41 to VII-43

	b_i-values in following models		
Variate	VII-41	VII-42	VII-43
YRS-CP[a]	0.9636	0.8758	0.9207
YRS-CP^2	-0.0001	-0.0031	0.0010
YRS-CP*PLDEN	-0.0074	-0.0065	-0.0076
*NCODE	0.0134	0.0119	0.0132
*SLOPE	-0.0043	-0.0152	-
*EROS	-0.0818	-	-0.0734
YRS-TERR[b]	3.5029	3.0534	2.3534
YRS-TERR^2	-0.0294	-0.0288	0.0050
YRS-TERR*PLDEN	-0.0204	-0.0227	-0.0229
*NCODE	0.0301	0.0302	0.0164
*SLOPE	-0.2728	-0.0371	-
*EROS	0.8440	-	0.2831

[a] YRS-CP = effect of years contour planted and $b_i = \Sigma b_i$ of YCPLANT1 and YCPLANT2 variates in Table 33.

[b] YRS-TERR = effect of years terraced and $b_i = \Sigma b_i$ of YCPLANT1 and YTERR variates in Table 33.

YRS-TERR are illustrated in Table 35. These responses were computed from simplified equations for combinations of two fixed levels of the interacting variables. These levels were in the midpart of the ranges, not the extremes. The yield responses to YRS-CP varied some with moderate changes in levels of the other variables. At higher PLDEN levels most of the responses would have been negative. The responses to YRS-TERR were quite variable (Table 35), particularly for the changes in SLOPE and EROS. For example, the ΔY at YRS-TERR = 20 decreased 27 bushels per acre as SLOPE changed from 5 to 10% and increased 17 bushels as EROS changed from 1 to 2. These are irrational responses.

Henao (1976) showed that the presence of highly correlated variables in a model often caused distortion of their regression coefficients, particularly those of their interactions with the same variable. The highly correlated variables do not affect greatly the use of the regression model for predicting yields, provided it is used for a population having similar correlations between the variables. Howevever, if the regression is used to study relationships (the effect of one variable on yield at fixed levels of others), rather severe distortions or biases may occur, depending on the degree of correlation. This occurs because two highly correlated variables in the population do not vary independently over a wide range; they have joint effects and their independent effects cannot be segregated.

Table 35. Changes in corn yield due to years contour planted and terraced at different levels of the interacting variables, MODEL VII-41[a]

Level of interacting variable				ΔY at YRS-CP =		YMAX at YRS-TERR	ΔY at YRS-TERR =	
PLDEN	NCODE	SLOPE	EROS	10	20		10	20
130	20	5	1	1.7	3.3	16	6.4	6.9
			2	0.8	1.6	30	14.8	23.8
		10	1	1.4	2.8	-	-7.3	-20.4
			2	0.6	1.2	7	1.2	-3.5
	30	5	1	3.0	5.9	21	9.4	12.9
			2	2.2	4.3	35	17.8	29.8
		10	1	2.8	5.5	-	-4.2	-14.4
			2	2.0	3.9	12	4.2	2.5
150	20	5	1	0.2	0.4	9	2.3	-1.3
			2	-0.6	-1.2	23	10.7	15.6
		10	1	0.0	-0.1	-	-11.3	-28.6
			2	-0.8	-1.7	0	-2.9	-11.6
	30	5	1	1.5	3.0	14	5.3	4.8
			2	0.7	1.4	28	13.8	21.6
		10	1	1.3	2.6	-	-8.3	-22.5
			2	0.5	0.9	5	0.1	-5.6

[a] YMAX and ΔY values computed from the coefficients given in Table 34. Response to YRS-CP was essentially linear with YMAX occurring at YRS-CP > 100 years for all except those combinations giving a negative response.

Because the SLOPE and EROS variables were highly correlated (r = 0.62), two additional models were computed. In MODEL VII-42, the EROS variates were deleted and in MODEL VII-43, the SLOPE variates were deleted. In these models, the effect of one variable on yield is determined allowing the other variable to vary naturally, depending on the degree of correlation. The effect of EROS, for example, on yield includes its direct effect plus the indirect effect of SLOPE through their correlation.

The regression statistics for MODELS VII-42 and VII-43 are also given in Table 33, the summed coefficients for their YRS-CP and YRS-TERR variates are given in Table 34, and the changes in yields for different combinations of the interacting variables are given in Table 36.

MODEL VII-43 containing the EROS variates gave a higher R^2 than MODEL VII-42 with the SLOPE variates. The regression coefficients were similar for most variates in all models except that those for the erosion control variates decreased in magnitude and significance in MODEL VII-42 and even more so in MODEL VII-43 (Table 33).

The summed coefficients for the YRS-CP variates were similar in all three models except that the coefficient for the YRS-CP*SLOPE interaction increased in MODEL VII-42 and the sign of the squared term changed from negative to positive in MODEL VII-43 (Table 34). The summed coefficients for YRS-TERR*SLOPE and YRS-TERR*EROS decreased markedly in

Table 36. Changes in corn yield due to years contour planted and terraced at different levels of the interacting variables, MODELS VII-42 and VII-43

Level of interacting variable				YMAX or YMIN at YRS-CP[a]	ΔY at YRS-CP =		YMAX or YMIN at YRS-TERR[a]	ΔY at YRS-TERR =	
PLDEN	NCODE	SLOPE	EROS		10	20		10	20
MODEL VII-42 (without EROS variates)									
130	20	5	-	31	1.6	2.6	9	2.3	-1.1
		10	-	19	0.9	1.1	6	0.5	-4.8
	30	5	-	50	2.8	5.0	14	5.4	4.9
		10	-	38	2.1	3.5	11	3.5	1.2
150	20	5	-	10	0.3	0.0	1	-2.2	-10.2
		10	-	-	-0.4	-1.5	-	-4.1	-13.9
	30	5	-	29	1.5	2.4	6	0.8	-4.1
		10	-	17	0.8	0.9	3	-1.0	-7.9
MODEL VII-43 (without SLOPE variates)									
130	20	-	1	-	1.3	2.9	1	0.4	1.8
		-	2	-	0.6	1.4	-	3.2	7.4
	30	-	1	-	2.6	5.5	-	2.0	5.0
		-	2	-	1.9	4.0	-	4.8	10.7
150	20	-	1	14	-0.2	-0.2	47	-4.2	-7.4
		-	2	51	-0.9	-1.6	19	-1.4	-1.7
	30	-	1	-	1.1	2.5	31	-2.6	-4.1
		-	2	-	0.4	1.0	2	0.3	1.5

[a] YRS-CP and YRS-TERR are associated with YMAX for MODEL VII-42 and with YMIN for MODEL VII-43. If not shown, responses were increasing or decreasing at an increasing rate.

MODELS VII-42 and -43, respectively. The sign of the YRS-TERR^2 variate also changed to positive in MODEL VII-43.

The changes in corn yield due to YRS-CP were similar in all three models (Tables 35 and 36) except that yield decrease due to increasing EROS in MODEL VII-43 was about half of that in MODEL VII-41. The changes in yield due to YRS-TERR in MODELS VII-42 and -43 were much less drastic than in MODEL VII-41. For example, the ΔY's as SLOPE varied from 5 to 10% at YRS-TERR = 20 were -27 and -3.7 bushels per acre in MODELS VII-41 and -42, respectively; the ΔY's as EROS varied from 1 to 2 erosion at YRS-TERR = 20 were 17 and 5.7 bushels per acre for MODELS VII-41 and -43, respectively.

The predicted yield responses to YRS-CP and YRS-TERR from both MODELS VII-42 and -43 were more rational than those from MODEL VII-41 showing that the high correlation between SLOPE and EROS was biasing the estimation of the erosion control effects in MODEL VII-41. The change in the shape of the response curves of both variables in MODEL VII-43, in which yields generally increased at an increasing rate due to the cumulative effect of years, appears to be more logical than the effects in the other two models. In all three models, however, the negative effects of increasing PLDEN on both YRS-CP and YRS-TERR appear due to biased estimates of the coefficients. This effect will be discussed later.

MODELS VII-44 to VII-46

In the MODEL II series (Table 16) and initial models of this series (Table 31), different response curves and ΔY's were noted for the YRS-TERR effect in the models containing all observations and those from which all contour planted only observations were deleted. These differences were investigated further by deleting the nonsignificant variates from MODEL VII-25 (272 contour planted observations deleted) and then deleting the remaining SLOPE and EROS variates alternatively as was done for MODELS VII-41 to -43. The R^2-values for these models, MODELS VII-44 to -46, are given in Table 32; their regression statistics, summed regression coefficients for YRS-TERR, and changes in yield due to YRS-TERR for different combinations of the interacting variables are given in Tables 37, 38, and 39, respectively.

Compared with the b_i-values for MODELS VII-41 to -43 (Table 34), those in MODELS VII-44 to -46 (Table 38) for linear YRS-TERR were smaller and of opposite sign, all of those for YRS-TERR^2 were positive, the one for the YRS-TERR*SLOPE in MODEL VII-45 (SLOPE alone) became positive, but the rest were similar.

The changes in corn yield due to YRS-TERR in MODEL VII-44 (including both SLOPE and EROS) were not quite as variable as for the comparable MODEL VII-41 (Tables 35 and 39). The ΔY at YRS-TERR = 20 decreased 16 bushels per acre for the SLOPE change and increased 13 bushels for the EROS change, still

Table 37. Regression statistics for the final models of corn yield on selected variates, MODELS VII-44 to VII-46 (n=350)

Variate	b_i-values for variates in following models MODEL VII-44	 MODEL VII-45	 MODEL VII-46
PLDEN	0.265	0.245	0.162
RL3	0.563^{+}	0.655^{++}	0.607^{+}
CRW	0.924^{++}	0.846^{+}	0.792
CB1	1.693**	1.552**	1.645**
CB2	0.0843^{++}	0.0984*	0.0761^{+}
WEEDS	-0.0650**	-0.0680**	-0.0674**
YCPLANT1	-9.2718**	-9.2481**	-3.1380
YTERR	8.8733*	8.0971*	1.7560
PLDATE	0.363	0.274	0.318
N	0.159*	0.172*	0.159*
P	-0.531	-0.466	-0.625
NCODE	-3.066**	-3.265**	-3.027**
PRES1	0.366**	0.320*	0.349**
SLOPE	-0.209	-0.317	-
PH1	7.819**	8.671**	8.855**
STN	-0.128	-0.117	-0.090
STP1	1.536**	1.603**	1.531**
EROS	-0.706	-	-1.215
CPL	5.969*	5.873*	5.701^{++}
STP3	0.0508	0.0406	0.0394
EM3V	-1.252*	-1.461**	-1.360*
DV	47.91^{+}	42.80	39.81
PLDEN^{2}	-0.0011^{+}	-0.0011^{+}	-0.0010^{+}
CB1^{2}	-0.0846**	-0.0809**	-0.0849**
YCPLANT1^{2}	0.1839**	0.1687**	0.0905*
YTERR^{2}	-0.1681**	-0.1434*	-0.0478
N^{2}	-0.0012^{++}	-0.0013^{++}	-0.0012^{++}
P^{2}	-0.0128*	-0.0134*	-0.0119*
NCODE^{2}	0.0322**	0.0370**	0.0349**

Table 37. (Continued)

Variate	b_i-values for variates in following models MODEL VII-44	 MODEL VII-45	 MODEL VII-46
PH1^2	-0.0604**	-0.0667**	-0.0683**
STP1^2	-0.0150**	-0.0155**	-0.0142**
CPL^2	-0.1202*	-0.1183*	-0.1163*
DV^2	-10.290*	-9.192++	-9.321*
PLDEN*YCPLANT1	0.0381**	0.0249*	0.0133+
*YTERR	-0.0624**	-0.0524**	-0.0393**
*P	-0.0047++	-0.0043+	-0.0040+
*DV	0.1820++	0.1871++	0.2081*
RL3*DV	-0.2523++	-0.2827*	-0.2650++
CRW*PLDATE	-0.0383*	-0.0339++	-0.0353++
*P	-0.0212++	-0.0215++	-0.0189++
YCPLANT1*NCODE	-0.1979**	-0.0830	-0.0479
*SLOPE	0.3222**	0.1429+	-
*STN	-0.0004	0.0216	0.0073
*EROS	-0.7801**	-	-0.4631*
YTERR*NCODE	0.2338**	0.1185++	0.0725
*SLOPE	-0.4829**	-0.1112	-
*STN	0.0502++	0.0354	0.0473+
*EROS	1.4513**	-	0.7989**
N*P	0.0069*	0.0067*	0.0066*
P*NCODE	0.0202*	0.0231**	0.0200*
*PH1	0.0163*	0.0138++	0.0156++
NCODE*STN	0.0169++	0.0158++	0.0154++
*STP1	-0.0089	-0.0095+	-0.0107++
PRES1*STP3	-0.0099*	-0.0090++	-0.0088++
Intercept	-350.59**	-367.61**	-362.86**

Table 38. Summed regression coefficients for the effect of years terraced, MODELS VII-44 to VII-46 (n=350)

	Σb_i of YCPLANT1 and YTERR variates		
Variate	VII-44	VII-45	VII-46
YRS-TERR	-0.3985	-1.1510	-1.3820
YRS-TERR^2	0.0158	0.0253	0.0427
YRS-TERR*PLDEN	-0.0243	-0.0275	-0.0260
*NCODE	0.0359	0.0355	0.0246
*SLOPE	-0.1607	0.0317	-
*STN	0.0498	0.0570	0.0546
*EROS	0.6712	-	0.3358

irrational yield responses. Deletion of the SLOPE or EROS variates decreased the yield responses as in MODELS VII-41 to 43.

The SLOPE increment had a positive effect on ΔY due to YRS-TERR in MODEL VII-45 compared to a negative effect in MODEL VII-42. Most of the ΔY's at YRS-TERR = 10 were similar in the two models but all at YRS-TERR = 20 years were more positive or less negative in MODEL VII-45 than in MODEL VII-42.

The EROS changes on ΔY due to YRS-TERR were only slightly larger in MODEL VII-46 than in VII-43. All ΔY's, however, were some less at YRS-TERR = 10 and larger at YRS-TERR = 20 in MODEL VII-46 than in VII-43.

Table 39. Changes in corn yield due to years terraced at different levels of the interacting variables, MODELS VII-44 to VII-46 (n=350)[a]

Level of interacting variable				YMIN at YRS-TERR	ΔY at YRS-TERR =	
PLDEN	NCODE	SLOPE	EROS		10	20
MODEL VII-44 (with SLOPE and EROS)						
130	20	5	1	-	2.7	8.6
			2	-	9.4	22.1
		10	1	22	-5.3	-7.4
			2	1	1.4	6.0
	30	5	1	-	6.3	15.8
			2	-	13.0	29.2
		10	1	10	-1.7	-0.3
			2	-	5.0	13.2
150	20	5	1	12	-2.1	-1.1
			2	-	4.6	12.3
		10	1	37	-10.2	-17.2
			2	16	-3.4	-3.7
	30	5	1	0	1.5	6.1
			2	-	8.2	19.5
		10	1	26	-6.6	-10.0
			2	5	0.1	3.5
MODEL VII-45 (EROS deleted)						
130	20	5	-	6	-0.7	3.6
		10	-	3	0.9	6.8
	30	5	-	-	2.8	10.7
		10	-	-	4.4	13.9
150	20	5	-	17	-6.2	-7.4
		10	-	14	-4.6	-4.2
	30	5	-	10	-2.6	-0.2
		10	-	7	-1.1	2.9
MODEL VII-46 (SLOPE deleted)						
130	20	-	1	6	-1.2	6.1
		-	2	2	2.1	12.8
	30	-	1	4	1.2	11.0
		-	2	-	4.6	17.7
150	20	-	1	13	-6.4	-4.3
		-	2	9	-3.1	2.4
	30	-	1	10	-4.0	0.6
		-	2	6	-0.6	7.3

---

[a] All ΔY's were computed with STN fixed at its mean of 62 pp2m.

Discussion

Both the initial and final models of corn yield on YRS-CP showed similar effects on yield. The positive cumulative effects of YRS-CP on yield were nearly linear in most models. The significant interactions between YRS-CP and PLDEN, NCODE, SLOPE, and EROS indicated that contouring effects on yield are influenced by management and soil variables. The one with PLDEN appeared to be distorted and will be discussed later. The positive interaction with NCODE showed that contouring effects increased as the crop sequence changed from first-year to continuous corn. This effect was expected.

Negative interactions between YRS-CP and the SLOPE and EROS variables showed that the contouring effect was larger on the less sloping and eroded soils than on the steeper, eroded ones. The yield responses to YRS-CP were little affected by the high correlation between SLOPE and EROS. In general, the yield responses became near zero at slopes greater than 10% and on the severely eroded soils. This agrees generally with previous research that the contouring effect on soil and water losses and yield reaches a maximum in the 3-7% slope range and becomes relatively ineffective on steeper slopes (Beasley, 1972).

The YRS-TERR effect on yields was more variable than the YRS-CP effect in the different models and was somewhat higher in the models in which the direct effect of YRS-TERR was estimated by deleting the contour planted only observations. However, a slightly different population occurred in the latter model. The high correlation between SLOPE and EROS ($r = 0.62$ for all observations and $r = 0.70$ for all except contour planted only) was shown to cause distorted regression coefficients in the models in which both variables were included. Retaining the EROS variates and deleting the SLOPE variates gave final models with slightly higher R^2.

The method of adding the YCPLANT2 variates in the final modeling stages and summing coefficients of 2 of the 3 erosion control variates to determine the YRS-CP and YRS-TERR effects gave results comparable to the direct estimations of these effects using models with fewer observations. In the initial modeling stages, only the YRS-TERR effect could be determined. This method increases the number of variates to be tested at all stages but this only adds some to the cost and time of analysis.

One effect that was quite consistent in all models was the negative interactions between the erosion control and PLDEN variables. The reason for these apparent distortions in the regression coefficients was not resolved in this study. Some confounding between erosion control variables and PLDEN may be present and not accounted for by the variates included. The PLDEN and N levels were lower in Harrison and Woodbury counties in the Ida-Monona area than in the other counties (Appendix Table A2). In one model (not shown), the interaction variates between erosion control variables and PLDEN were deleted and then the interactions between erosion control variables and N became significant. The negative interactions with N gave a similar effect as those with PLDEN; as N rates increased above the mean of about 62 lb/acre, the yield response to YRS-CP and YRS-TERR decreased and then became negative. PLDEN and N were positively correlated (r = 0.46).

Only about one-third of the possible interactions among the variables were tested; some important ones may have been missed. If some confounding is related to the observations from the Ida-Monona area compared to the Marshall and Sharpsburg areas, some interactions with the RANGE (E to W distance) variable may be important to test. Another way that might improve the yield predictions is to run alternative regression models using observations from the Ida-Monona and from the Marshall and Sharpsburg areas, omitting the observations from the till and paleosol soils.

Many of the management, soil, and weather variables had highly significant linear, curvilinear, and interaction effects on corn yield. Although discussion of their effects was minimized in this final section, they explained much more of the yield variation than the erosion control variables, as would be expected. Their effects can be examined from the regression statistics presented.

Several preliminary regressions were run to determine the cumulative effects of erosion control variables on soil test N, P, and K levels. Others were run by regressing several of the variables alternatively on all the rest, including the erosion control variables, to determine associations for possible causes of the confounding discussed previously. Examination of these in detail was beyond the scope of this thesis.

SUMMARY AND CONCLUSIONS

Soil erosion has been and is a serious agricultural problem of the sloping soils in southwestern Iowa. Much of the research work on erosion control practices has been concerned with soil and water losses and the subsequent depletion of organic matter and plant nutrients in these soils. Little research, however, has been done to investigate how erosion control practices affect corn yields over a range of soil, management, and weather conditions.

The major objective of this research was to study the effects of conservation practices on corn yields by constructing a yield model to include the most important soil erosion control, management, environment, weather, and soil variables. Initially, important variables were selected from linear and quadratic multiple regression models and then interaction terms were added for the final multiple regression models of yield on selected linear, quadratic, and interaction terms.

The source of the yield and other data was a long-term, state-wide soil productivity project entitled: Corn yielding capacity of Iowa soil types under different soil and crop management and climatic conditions. For this study, 622 observations from 1958-1970 were used from the upland soils from five western and southwestern Iowa counties: Adams, Cass, Crawford, Harrison, and Woodbury. This area was selected because use of erosion control practices has been more prevalent than in other areas. The soils were in the Shelby-Sharpsburg-Macksburg, Marshall, and Monona-Ida-Hamburg soil association areas.

Most of the soil, management, and weather variables had been listed for a previous statewide yield study (Henao, 1976). For this study, variables for some tillage practices, the erosion control practices, and a few weather variables were added.

The variables included environmental variables such as time trend, corn insect and weed infestations, barren stalks, silking date, and root and stalk lodging. Weather variables included excess moisture and moisture stress indexes, supplemented by simple rainfall measurements. Management variables were plant density, planting date, total N, P, and K from manure and fertilizer, N, P, and K fertilizer, manure, residual amounts of applied N and P from manure and fertilizers, crop sequence, and ratio of slope of rows to slope of site area. Tillage methods and number of tillage operations were also included. Six erosion control variables were included initially; these were contour plowed (CPLOW) and contour planted (CPLANT) designated by 0 and 1 dummy variables, distance to terrace above site (DTERR), and cumulative effects of years contour plowed (YCPLOW), years contour planted (YCPLANT1), and years terraced (YTERR). The soil variables included soil test values of the plow layer and subsoil; slope characteristics; drainage, permeability, bulk density, clay distribution and plant available water capacity; organic carbon level, depth of A horizon, and erosion class; and parent material.

Since the YCPLANT1 and YTERR variables in the initial testing did not give the unconfounded effects of both years contour planted and terraced, another erosion control variable (YCPLANT2 or years contour planted at only the contoured sites) was added in the final model selection stages. The YCPLANT1 variable compared years contour planted only and terraced vs noncontoured sites; the YCPLANT2 variable compared years contour planted vs terraced and noncontoured sites; and YTERR compared years terraced vs contour planted only and noncontoured sites. The sum of the two regression coefficients for each of the YCPLANT1 and YCPLANT2 variates (linear, squared, and interaction terms) gave the unconfounded effects of years contour planted; the sum of the coefficients for each of the YCPLANT1 and YTERR variates gave the unconfounded effects of years terraced.

This method was compared to models in which all terraced observations were deleted (to give a direct comparison of years contour planted vs noncontoured) and in which all contour planted observations were deleted (to give a direct comparison of years terraced vs noncontoured).

In the first series of regressions (MODEL I series), 70 variables were included. Correlation analysis showed that many of these were highly intercorrelated, particularly within groups such as organic matter related, clay related, pH related, etc. Multiple linear regressions of yield were run in a series of models and 50 variables were retained for further testing. Variables deleted had nonsignificant effects or were highly correlated with other more significant variables. The R^2 of the 70-variable model was 0.765. Deletion of the barren stalk (BARR) and silking date (SLKDATE) variables (both more yield component than independent variables) reduced the R^2 to 0.521. Deletion of more variables gave a final R^2 of 0.486.

In the next series of regressions (MODEL II series), quadratic functions of 48 variables (linear and squared terms) plus linear effects of 2 variables were tested. The R^2 of the initial model (excluding BARR and SLKDATE) was 0.658. In a series of alternative models, the significant variables, the most significant variables of highly correlated pairs, and 2 (YCPLANT1 and YTERR) of 5 erosion control variables were selected for further testing. The R^2 of the final model in this series of testing had 49 variates and an R^2 of 0.623.

At this stage of the model selection, the YCPLANT2 variable was added. It along with YCPLANT1 and YTERR were used to estimate the unconfounded effects of years contour planted and terraced. The three erosion control variables were then tested in various combinations using all 622 observations. Regression models were also run with the 79 terraced sites deleted (n=543) to test the direct effect of years contour planted and with 272 contour planted only observations deleted (n=350) to test the direct effects of years terraced.

In the quadratic models, the yield responses (ΔY) to years contour planted were small but similar in all models. The ΔY decreased slightly in the first few years and then increased to about 1.7 bushels per acre after 20 years contour planted. Yield responses to years terraced were larger than to years contour planted and showed the same trend in all models by increasing up to 3-7 bushels per acre in 8-10 years after terracing and then decreasing. Yield responses were larger in the models from which contour planted only observations were deleted than those from models using all observations.

The effects of the erosion control practices may be confounded with other factors because of unequal distribution of the practices in the different counties and a higher percentage of use on the steeper and lower productivity soils.

The final quadratic model selected (n=622) included 29 linear and 18 squared variates and had an R^2 of 0.620. Most of the variables had the expected effects on corn yield although the effects of some variables were not estimated very well because interactions were not present.

In the MODELS III, IV, and V series, 43, 44, and 44 interaction variates were tested with a base set of 45 linear and squared terms. These regressions were run prior to the addition of the YCPLANT2 variable; their value was to select the most significant interactions involving variables other than the erosion control ones. Since the computer program could handle only 100 variables, the number of interactions had to be reduced for the final regression models. From the three final models, a total of 42 interactions were retained for further testing. The R^2 of the final models varied from 0.643 to 0.663.

The MODEL VI series, which was also run before the YCPLANT2 variable was added, combined all variates which had been selected in previous models. The BARR and SLKDATE variables were included in one set of regressions; the R^2 of 0.827 for the final model which included 15 interaction terms was little higher than that of the quadratic model. The final model without BARR and SLKDATE included the interaction terms and had an R^2 of 0.687 compared to 0.620 for the final quadratic model. Most of the interaction effects involving the soil, management, and weather variables were in the expected direction.

In the final MODEL VII series, the YCPLANT2 variable was added along with 14 additional interactions with YCPLANT1, YCPLANT2, and YTERR. The initial model (without the BARR and SLKDATE variables) contained 46 linear and squared variates and 48 interaction variates including 21 with the erosion control variables. The R^2 was 0.709 for the initial model utilizing all 622 observations. Additional models were run by alternatively deleting the 79 terraced and 272 contour planted only observations. R^2-values of the final models for all observations and all except the 272 contour planted sites were 0.691 and 0.746, respectively.

The cumulative effects of years contour planted (YRS-CP) were generally positive and nearly linear in most models. Significant interactions between YRS-CP and plant density (PLDEN), position of the corn in the crop sequence (NCODE), SLOPE, and erosion class (EROS) showed that contouring effects on yield were influenced by management and soil variables. The YRS-CP effects were larger on the less sloping and eroded soils than on steeper, less eroded ones, and were little affected by the high correlation between SLOPE and EROS. Yield responses generally became near zero at slopes greater than 10%; this effect agrees with previous research that contouring becomes relatively ineffective on the steeper slopes.

The cumulative effects of years terraced (YRS-TERR) were generally positive but variable in different models. They were affected by interactions with the same variables as the YRS-CP effects were. Yield responses were somewhat higher in the models in which the direct effect of YRS-TERR was estimated by deleting contour planted only observations, but the sampled populations were some different. The high correlation between SLOPE and EROS caused distorted regression coefficients and large variations in yield responses to YRS-TERR in the models including both variables. Retaining the EROS variates and deleting the SLOPE variates gave final models with more rational estimates of the YRS-TERR effects.

The method of adding the YCPLANT2 variates in the final modeling stages and summing coefficients of 2 of the 3 erosion control variates to determine the YRS-CP and YRS-TERR effects gave satisfactory results.

One effect that was consistent in all models was the large negative interactions between the erosion control and PLDEN variates. Yield responses to YRS-CP and YRS-TERR were reduced at moderate plant densities and became negative at higher levels. The reason for the apparent distortions in these interaction coefficients was not ascertained in this study.

Some confounding in the PLDEN-erosion control effects may be due to the lower PLDEN in the Ida-Monona area than in the others. Also, a higher percentage of the steeper and lower productivity soils had erosion control practices and lower PLDEN than the others. Only about one-third of the possible interactions were tested; some important ones may have been missed. The others should be tested before any other regression analyses. Another approach is to analyze separately the observations from the Ida-Monona and from the Marshall-Sharpsburg areas, excluding observations from the till and paleosol units.

Many of the management, soil, and weather variables had highly significant linear, curvilinear, and interaction effects on yield. Although discussion of their effects was minimized in this study, they explained much more of the yield variation than the erosion control variables. Their effects can be examined from the regression statistics presented.

This research project was not initiated to study specifically the effects of erosion control practices on corn yields. Another possible source of confounding and high correlations between many of the variables may be due to the random selection of sites within the selected counties. Consequences of such a method is unequal distributions of erosion control practices over the ranges of the variables such as SLOPE, EROS, PLDEN, and other management. Any future research should use a stratified sampling system to obtain a better distribution of erosion control variables over the wide range of the other variables and to minimize correlations between variables.

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APPENDIX

Table A1. Data listing for erosion control, management, environment, soil, and weather variables on computer cards 31, 32, and 33

X_i	Column no.	Identification or variable
-	1-2	Card no. = 31
-	3-4	County code (Adams = 02, Cass = 15, Crawford = 24, Harrison = 43, Woodbury = 97)
-	5-6	Year (last 2 digits)
-	7-8	Site number
1	9-11	Corn yield to the nearest whole bushel per acre (adjusted for estimated yield loss due to hail and disease damage)
2	12-13	Time trend, coded 1957 = 1 to 1974 = 14
3	14-16	Plant density (total stalks per acre) at harvest, listed as stalks per 1/100 acre
4	17-18	Percent of stalks which were barren
5	19-20	Average ear weight (pound per stalk). listed as average ear weight x 100
6	21-22	Percent of stalks moderately root lodged at harvest leaning between 30° and 60° from vertical (100% = 99)
7	23-24	
8	25-26	Total percent of stalks moderately and severely root lodged at harvest (100% = 99)
9	27-28	Corn root damage due to corn rootworms based on Dr. D. C. Peters' rating scale of 1.0 (none) to 6.0 (most severely damaged, listed as rating*10
10	29-30	Percent of stalks broken over below the ear node at harvest (100% = 99)
11	31-32	Percent of stalks broken over at or above the ear node at harvest (100% = 99)
12	33-34	First brood corn borer infestation, listed as number of cavities (feeding areas) per 10 stalks
13	35-36	Second brood corn borer infestation, listed as the number of cavities per 10 stalks (100 or more = 99)
14	37-39	Grassy weeds, listed as lb (air-dry) per 0.1 acre
15	40-42	Broadleaf weeds, listed as lb (air-dry) per 0.1 acre
16	43-45	Total weeds (grassy + broadleaf), listed as lb per 0.1 acre
17	46	2,4-D spray application, listed as 0 = none, 1 = once, 2 = twice, and 3 = 3 times

Table A1. (Continued)

X_i	Column no.	Identification or variable
18	47	Number of times corn harrowed after planting + rotary hoed + cultivated
19	48	Field plowed on the contour, listed as 0 = not contour plowed and 1 = contour plowed
20	49	Field planted on the contour, listed as 0 = not contour planted and 1 = contour planted
21	50-52	Distance in feet to top of terrace ridge above site, coded as: 200 - distance in feet (>200 ft or not terraced = 0)
22	53-54	Number of years to date that field was contour plowed (not contour plowed = 0)
23	55-56	Number of years to date that field was contour planted (not contour planted = 0)
24	57-58	Number of years to date since terrace was built within 200 feet above the site (no terrace or >200 ft = 0)
25	59	Seedbed preparation: fall moldboard and others = 0, spring moldboard = 1
26	60	Seedbed preparation: moldboard (fall or spring = 0, all others = 1)
27	61	Number of tillage operations before plowing (single disked + others)
28	62	Number of tillage operations after plowing (single disked + spring-toothed + harrowed + others)
29	63-64	Date planted: in April = April date - 20; in May = May date + 10; and in June = June date + 41
30	65-66	Date 75% silked: in July = July date and in August = August date + 31
31	67-68	Average row width (to nearest inch - 28")
32	69-70	Manure application, tons/acre
33	71-73	Total N applied from manure and all fertilizer applications (lb N/acre)
34	74-75	Total P applied from manure and all fertilizer applications (lb P/acre)
35	76-78	Total K applied from manure and all fertilizer applications (lb K/acre)

Table A1. (Continued)

X_i	Column no.	Identification or variable
	1-2	Card no. = 32
	3-4	County no.
	5-6	Site no.
36	9-11	N applied in fertilizer, lb N/acre
37	12-13	P applied in fertilizer, lb P/acre
38	14-16	K applied in fertilizer, lb K/acre
39	17-18	Cropping code for N availability (corn in current year underlined): $\underline{C}$-M-M = 08 $\underline{C}$-Sb-M-M = 08 $\underline{C}$-M = 10 $\underline{C}$-Sb-M = 10 $\underline{C}$-O_M = 15 $\underline{C}$-Sb-O_M = 14 $\underline{C}$-C-M-M = 17 $\underline{C}$-Sb-C-M-M = 15 $\underline{C}$-C-M = 20 $\underline{C}$-Sb-C-M = 17 $\underline{C}$-C-O_M = 25 $\underline{C}$-Sb-C-O_M = 20 $\underline{C}$-C-C-M = 30 $\underline{C}$-Sb-C-C-M = 25 $\underline{C}$-C-C-O_M = 35 $\underline{C}$-Sb-C-C-O_M = 30 $\underline{C}$-C-C-C (cont. corn) = 40 $\underline{C}$-Grass-Grass = 30 $\underline{C}$-Sb-C-C-C = 35 Abbreviations: C = corn, M = legume-grass meadow, O_M = oats and legume seeding, and Sb = soybeans
40	19-20	Cropping code for K availability: Corn after: 3 or more years of corn or after diverted (idle or set-aside) acres 00 2 years of corn 05 Corn, oats or oats and green manure 10 Soybeans 20 Soybeans (2 or more years) 30 1 year of meadow (pastured) 30 1 year of meadow (hay and pasture) 35 1 year of meadow (hay) or corn silage 40 2 or more years of meadow (pastured last 2 years) 40 2 or more years of meadow (hay and pasture last 2 years) 50 2 or more years of meadow (hay) or corn silage 60

Table A1. (Continued)

X_i	Column no.	Identification or variable
		Total nutrients applied previous year from fertilizer and manure
41	21-23	lb N/acre
42	24-25	lb P/acre
43	26-28	lb K/acre
		Total nutrients applied 2 years previously from fertilizer and manure
44	29-31	lb N/acre
45	32-33	lb P/acre
46	34-36	lb K/acre
		Total nutrients applied 3 years previously
47	37-39	lb N/acre
48	40-41	lb P/acre
49	42-44	lb K/acre
50	45-46	% slope of site areas
51	47-48	% slope of corn rows through harvest area
52	49-50	Ratio: $\frac{\text{\% slope of rows}}{\text{\% slope of site}} \times 100$ (rows fully on contour = 00 and rows up and down hill = 99)
53	51	Aspect (direction of slope) of site, coded: 1 = SSW 2 = S or SW 3 = SSE or WSW 4 = SE or W 5 = ESE or WNW 6 = E or NW 7 = ENE or NNW 8 = NE or N 9 = NNE
54	52	Row direction, coded: 1 = E-W 3 = ESE-WNW or ENE-WSW 5 = NE-SW or SE-NW 7 = SSE-NNW or NNE-SSW 9 = N-S
		Soil tests of plow layer from sample taken at harvest
55	53-54	pH listed as: actual pH (nearest tenth)*10
56	55-56	Buffer pH listed as: (actual buffer pH-6.00) *100 (buffer pH $\geq$ 7.00 to be listed as 99)
57	57-58	N(moist): pp2m N in field moist sample (>99 = 99)

Table A1. (Continued)

X_i	Column no.	Identification or variable
58	59-60	P: pp2m P (>90 = 90)
59	61-63	K: pp2m K in field moist sample (>999 = 999)
60	64-66	Soil test K (>350 = 350)
61	67-68	Township number (T65 to T89)
62	69-70	Range number (R32 to R47)
63	71	Slope configuration, coded: 1 = strongly convex 2 = convex 3 = convex to straight 4 = straight (flat) 5 = straight to concave 6 = concave
64	72	Erosion class, coded: 0 = none (>12" A horizon) 1 = slight (7-12" A horizon) 2 = moderate (3-7" A horizon) 3 = severe (<3" A horizon)
65	73-74	Depth of A horizon ($A_1 + A_2 + A_3$) in inches
66	75-76	Estimated % organic carbon of 0-7" layer, coded % OC*10)
67	77-78	Estimated % OC of 7-20" layers, coded weighted average
68	79-80	Weighted average of % organic carbon in 0-20" layer (% OC to nearest tenth*10)
	1-2	Card no. = 32
	3-4	County code
	5-6	Year
	7-8	Site number
69	9-10	Natural internal drainage, coded: 10 = excessive 20 = excessive to well 30 = well 40 = moderately well 50 = somewhat poor 60 = somewhat poor 70 = poor 80 = poor to very poor 90 = very poor

Table A1. (Continued)

X_i	Column no.	Identification or variable
70	11-12	Subsoil permeability, coded: 00 = very rapid 10 = rapid 20 = rapid to mod. rapid 30 = moderately rapid 40 = mod. rapid to moderate 50 = moderate 60 = moderate to slow 70 = slow 80 = slow to very slow 90 = very slow
71	13-14	% clay in plow layer (nearest whole number)
72	15-16	Maximum % clay in subsoil (below plow layer)
73	17-18	Depth (inches) to midpoint of horizon(s) with maximum % clay
74	19	Subsoil group rating for crop growth, coded: 0 = very favorable 1 = favorable 2 = slightly unfavorable 3 = slightly to mod. unfavorable 4 = moderately unfavorable 5 = mod. to very unfavorable 6 = very unfavorable
75	20	Biosequence, coded: 1 = forest 2 = forest-transition 3 = transition 4 = transition-prairie 5 = prairie
76	21-22	Bulk density (g/cm^3) at 30-40 in. depth, coded: (BD - 1.00)*100
77	23	Subsoil structure in B horizon or comparable zone, coded: 1 = structureless (massive or single grain) 2 = structureless to weak 3 = weak 4 = weak to moderate 5 = moderate 6 = moderate to strong 7 = strong

Table A1. (Continued)

X_i	Column no.	Identification or variable
78	24-25	Depth to till in till mapping units (all other units = 0), coded: 60"-depth to till (>60" = 0)
79	26-27	Depth to paleosol in profile (all other units = 0), coded: 60"-depth to paleosol (>60" = 0)
80	28-29	Depth to till in loess over till mapping units (all other units = 0), coded: 60"-depth to till (>60" = 0)
81	30-31	Depth to deoxidized loess in loess mapping units (all other units = 0), coded: 60"-depth to deoxidized loess (>60" = 0)
82	32-33	Minimum pH in subsoil (below plow layer), coded: pH to nearest tenth*10
83	34-35	Depth (inches) to midpoint of minimum pH layer
84	36-37	Depth to top of carbonate horizon, coded: 60"-depth (>60" = 0)
85	38-39	pH of 30-42" zone, coded: pH*10
86	40-41	pH of 42-60" zone, coded: pH*10
87	42-43	Available P of 10-20" zone, pp2m P
88	44-45	Available P of 30-42" zone, pp2m P
89	46-48	Available K of 12-24" zone, pp2m K
90	49-53	Excess moisture index (energy weighted)
91	54-58	Moisture stress index (energy and growth stage weighted)
92	59-63	Total rainfall (inches) from 42 days before silking to 33 days after silking
93	64-68	Total rainfall (inches) from April 15 to 42 days before silking
94	69-73	Plant available water capacity, inches per 5 ft soil profile
95	74-78	Plant available water on April 15, inches per 5 ft soil profile

Table A2. County means of selected variables

X_i	Variable[a]	Adams	Cass	Crawford	Harrison	Woodbury
1	YIELD	105.3	101.7	102.6	89.0	92.6
3	PLDEN	133.7	134.6	138.5	125.5	132.6
4	BARR	5.5	5.5	5.2	6.6	6.4
8	RL3	12.5	14.8	11.5	19.8	6.6
12	CB1	3.4	2.8	4.0	2.6	4.5
13	CB2	19.6	16.6	21.2	22.9	26.3
16	WEEDS	54.8	67.7	53.9	38.8	44.6
19	CPLOW	0.46	0.59	0.29	0.62	0.43
20	CPLANT1	0.57	0.65	0.45	0.71	0.62
21	DTERR	14.8	6.3	7.7	53.5	9.4
22	YCPLOW	6.2	8.1	3.2	7.9	6.1
23	YCPLANT1	7.9	8.9	5.3	9.5	9.1
24	YTERR	1.5	1.4	0.6	5.3	0.4
29	PLDATE	25.8	25.8	25.1	28.1	25.3
32	MAN	1.9	2.0	1.7	1.3	2.6
33	N	54.1	70.8	63.1	54.2	53.7
34	P	13.0	13.5	15.1	14.8	17.8
35	K	20.2	23.3	18.2	16.4	24.0
36	NFERT	46.7	60.7	54.7	47.8	40.9
37	PFERT	9.8	9.0	11.4	12.0	12.2
38	KFERT	7.9	6.5	4.2	5.8	2.9
39	NCODE	20.8	20.9	18.2	22.0	20.1
40	KCODE	24.1	19.8	18.1	14.3	18.0
41	NRES1	20.5	46.4	25.6	18.2	24.0
42	PRES1	5.1	9.9	7.4	7.9	10.2
45	PRES2	6.3	8.9	6.8	9.3	11.7
48	PRES3	5.9	7.6	6.5	6.1	8.3
50	SLOPE	6.3	7.3	9.9	9.1	9.2
52	SLRATIO	40.4	27.2	34.1	24.3	33.9
55	PH1	62.1	62.3	64.2	70.5	70.7

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[a] County means are given only for the variables that showed variation from the overall means given in Table 3.

Table A2. (Continued)

X_i	Variable	Adams	Cass	Crawford	Harrison	Woodbury
56	PHB	62.2	65.8	70.9	84.7	85.1
57	STN	66.4	66.3	62.2	52.1	60.0
58	STP1	24.1	27.2	20.3	17.7	20.9
60	STK1A	248.4	262.1	219.1	230.3	233.4
61	TWP	72.0	75.4	83.6	79.3	87.9
62	RANGE	33.3	35.7	39.1	42.0	43.7
63	SLCONF	2.8	2.4	2.2	2.7	2.4
64	EROS	1.03	0.87	1.69	1.43	1.90
65	DAHOR	11.8	11.6	7.6	9.8	6.4
68	OCAV	13.6	13.9	10.2	11.2	9.2
69	DRAIN	45.9	38.1	31.9	30.0	30.0
70	PERM	64.9	64.1	49.3	39.5	42.8
71	CPL	29.2	28.7	27.1	23.0	24.7
72	CMAX	39.5	37.2	29.7	22.9	24.8
73	DCMAX	22.3	24.3	12.7	13.2	13.9
76	BD2	44.9	38.6	31.25	25.5	27.3
78	DPMT	6.9	3.9	4.3	0.0	0.0
79	DPMP	7.8	5.4	0.0	0.0	0.0
80	DPML/T	0.0	1.1	0.0	0.0	0.8
81	DPML	10.5	9.6	2.8	8.7	1.3
82	PHMIN	60.8	61.8	66.9	72.8	72.4
84	DCAL	7.6	2.3	14.5	25.8	31.9
86	PH3	69.2	67.1	71.4	76.2	77.4
88	STP3	18.5	24.2	17.5	10.1	11.5
89	STK2	66.6	70.9	49.4	68.7	48.4
90	EM3V	2.7	1.9	0.8	0.0	0.2
91	DEFCTV(DV)	2.7	2.5	2.5	2.5	2.4
92	PPT75	10.6	9.4	9.3	9.5	9.2
93	PPEAR	9.4	9.2	9.1	9.7	9.3
94	PAWC	10.3	10.6	11.3	11.8	11.6
95	PAW	7.7	7.8	7.1	7.1	5.7

Table A3. Simple correlation coefficients greater than ± 0.39 between variables, MODEL I series

Between variables		r-value	Between variables		r-value
TREND and	PLDEN	.56	N and	PFERT	.56
	N	.49		KFERT	.48
	NFERT	.53		NCODE	.40
	PFERT	.47		NRES1	.48
	KFERT	.48			
	PAW	-.46	P and	K	.65
				NFERT	.48
PLDEN and	N	.46		PFERT	.77
	NFERT	.48		KFERT	.46
	PFERT	.40		STP1	.40
CRW and	NCODE	.44	NFERT and	PFERT	.64
	KCODE	-.45		KFERT	.51
	NRES1	.42		NCODE	.45
				NRES1	.51
CPLOW and	CPLANT	.78			
	YCPLOW	.72	PFERT and	KFERT	.56
	YCPLANT1	.68			
	SLRATIO	-.50	NCODE and	KCODE	-.55
				NRES1	.61
CPLANT and	YCPLOW	.58		PRES1	.41
	YCPLANT1	.70			
	SLRATIO	-.63	NRES1 and	PRES1	.72
				STP1	.41
DTERR and	YTERR	.70			
			SLOPE and	PH1	.44
YCPLOW and	YCPLANT1	.88		PHB	.46
	YTERR	.46		STK1A	-.47
				EROS	.62
YCPLANT1 and	YTERR	.43		DAHOR	-.66
	SLRATIO	-.59		OCAV	-.67
				PHMIN	.51
SPRPLOW and	NONPLOW	-.50		DCAL	.49
				PH3	.45
PLDATE and	SLKDATE	.60		STK2	-.42
MAN and	P	.53	PH1 and	PHB	.88
	K	.96		RANGE	.50
				EROS	.55
N and	P	.67		DAHOR	-.52
	K	.43		OCAV	-.59
	NFERT	.91		PERM	-.52

Table A3. (Continued)

Between variables		r-value
PH1 and	CPL	-.71
	CMAX	-.66
	PHMIN	.90
	DCAL	.79
	PH3	.71
	STP3	-.47
PHB and	RANGE	.45
	EROS	.53
	DAHOR	-.53
	OCAV	-.61
	PERM	-.41
	CPL	-.51
	CMAX	-.53
	PHMIN	.76
	DCAL	.61
	PH3	.62
STN and	STP1	.42
	STK1A	.45
STP1 and	STK1A	.49
STK1A and	EROS	-.51
	DAHOR	.55
	OCAV	.56
	STK2	.58
TWP and	RANGE	.84
	DAHOR	-.46
	DRAIN	-.62
	PERM	-.56
	CMAX	-.58
	DCMAX	-.42
	BD2	-.43
	PHMIN	.47
	PAWC	.40
RANGE and	OCAV	-.40
	DRAIN	-.68
	PERM	-.74
	CPL	-.56
RANGE and	CMAX	-.77
	DCMAX	-.46
	BD2	-.56
	PHMIN	.64
	DCAL	.51
	PH3	.53
	STP3	-.40
	EM3V	-.43
	PAWC	.53
SLCONF and	EROS	-.43
	DAHOR	.50
	OCAV	.45
EROS and	DAHOR	-.93
	OCAV	-.90
	PHMIN	.62
	DCAL	.56
	PH3	.57
	STP3	-.45
	STK2	-.50
DAHOR and	OCAV	.94
	DCMAX	.44
	PHMIN	-.61
	DCAL	-.54
	PH3	-.59
	STP3	.51
	STK2	.64
OCAV and	CMAX	.43
	DCMAX	.45
	PHMIN	-.67
	DCAL	-.60
	PH3	-.64
	STP3	.53
	STK2	.59
DRAIN and	PERM	.76
	CPL	.48
	CMAX	.73
	DCMAX	.47

Table A3. (Continued)

Between variables		r-value
DRAIN and	BD2	.54
	DPMP	.58
	PHMIN	-.42
	EM3V	.49
	PAWC	-.52
PERM and	CPL	.68
	CMAX	.96
	DCMAX	.61
	BD2	.77
	DPMP	.68
	PHMIN	-.63
	DCAL	-.48
	PH3	-.46
	EM3V	.66
	PAWC	-.78
CPL and	CMAX	.78
	BD2	.43
	PHMIN	-.79
	DCAL	-.70
	PH3	-.64
	STP3	.45
	PAWC	-.44
CMAX and	DCMAX	.60
	BD2	.63
	DPMP	.56
	PHMIN	-.77
	DCAL	-.66
	PH3	-.64
	EM3V	.55
	PAWC	-.65
BD2 and	DPMT	.72
	DPMP	.55
	EM3V	.72
	PAWC	-.95
DPMT and	PAWC	-.69
DPMP and	EM3V	.58
	PAWC	-.56
PHMIN and	DCAL	.87
	PH3	.84
	STP3	-.60
DCAL and	PH3	.92
	STP3	-.63
PH3 and	STP3	-.74
EM3V and	PAWC	-.69
DV and	PPT75	.50
	PPTEAR	.44
	PAW	.40