CORN YIELDS AS A FUNCTION OF SPECIFIED PRODUCTION FACTORS EXPRESSED AS VARIABLES IN QUADRATIC PREDICTION EQUATIONS

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CHAPTER I

INTRODUCTION

Corn (Zea mays L.) is one of the major crops of American agriculture. It is a dual purpose crop since it is grown both for grain and forage. The grain is consumed directly and indirectly in different forms by human beings. A high quality silage is made from the forage for livestock. Thus the wide uses of corn indicate its importance. In United States the average per acre yield of corn is 61.8 bushels and the total production per year is 3.55 billion bushels.[1]

The productivity of land for a given crop is a function of three major influences--the soil, the climate, and the management practices. Each of these three major influences is made up of several components. The soil includes its physical, chemical, and biological conditions. The climate includes rainfall, temperature, light, etc. The management practices include the application of fertilizer, weed control, plant protection measures, tillage, cropping system, etc. Considerable efforts have been made in recent years to study the relationships between corn yields and one or more components. Probably less work has been done to study the relationships between corn yields and all the components together.

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[1] USDA Crop Production. Aug. 1962.

The need to predict corn yield on various soils with different types and amounts of management inputs under different environmental conditions has been recognized. Since soil types in Tennessee vary greatly in their capacity to produce corn, more precise prediction information is needed for farmers to better utilize their land and other resources by selecting an appropriate cropping system and management level.

The objectives of this study were:

1. to interpret rainfall and soil moisture information in terms of drought as one production factor;

2. to develop methodology for fitting appropriate drought values along with varying levels of selected management factors in quadratic prediction equations;

3. to develop a mathematical relationship in terms of a quadratic function between observed yields and varying levels of selected production factors;

4. to develop "effective" prediction equations for predicting corn yields; and

5. to make an agronomic interpretation of the findings of this study.

CHAPTER II

LITERATURE REVIEW

An important factor explaining variations in corn yields on different soil types is the nutrient status of the soil. Many plant nutrients are required for corn production and prominent among these nutrients is nitrogen. Smith (60) reported a high nitrogen requirement for corn and that each bushel of grain contained approximately one pound of nitrogen. A crop of corn producing 100 bushels of grain per acre required 160 to 215 pounds of nitrogen (24, 35, 60). Hunter and Yungen (22) found that the application of nitrogen fertilizers resulted in statistically significant increases in corn yields in 10 out of 13 experiments. They also found that in general, the higher yields were associated with greater plant populations, and that the magnitude of the yield increases resulting from the several levels of nitrogen was related to plant population. Maximum or near maximum yields were produced in most cases by the application of 100 pounds of nitrogen per acre.

Scarseth, et al. (56) stated, "corn plants that are growing in a soil very deficient in nitrogen, phosphorus, and potassium may show a shortage of phosphorus in its tissue until the plant is about twelve inches high; then nitrogen may become the limiting nutrient element and remain so until about maturity time, when potassium may show up as the limiting factor."

Long (35) reported that lodging was more severe under the conditions of potash deficiency and high plant population. Brooks (8) reported that potassium deficiency might result in weak stalks, lodging, small kernels that are light and apparently immature, weak cobs, and black discoloration in the nodes of stalks.

Krantz and Chandler (31) by applying potash on potash-deficient soils, decreased lodging and increased yields; however, some lodging occurred even where applied potash had no effect on yield and where there was excessive consumption of potash by the crop.

Heady, et al. (18) working with nitrogen and phosphorus, found a positive interaction between these two nutrients. They reported that the response to one nutrient was highly limited by the amount of the other nutrient. The highest yield could be obtained from use of the two nutrients in 1:1 ratio. For low rates of fertilizer applications greater response per pound could be obtained with nutrient ratios differing from 1:1.

Barber (3) found that phosphorus applied to build up the levels in the soil was effective in increasing the yields of each crop grown. Row applications increased yields most at the lowest phosphorus level and the effect of row applications decreased as the soil phosphorus level increased. The maximum production for a corn-soybean-wheat-hay rotation was obtained by using a high soil phosphorus level without row application.

From a three-year rotation study with corn and small

grain on Canfield silt loam soil Salter and Barnes (55) reported that corn yields increased at both levels (0 and 220 pounds) of applied superphosphate with an increasing pH (4.5 to 7.0). The superphosphate application also increased corn yields at all pH levels.

Considerable research has been conducted on the relationships among fertilization, moisture supply and plant population. Smith (60) working with 6, 8, 12, and 18 thousand plants per acre at different fertility levels obtained increasing yields up to 18 thousand plants per acre. As a result of these experiments he stated that in order to obtain maximum benefits from a high level of fertilization the rate of planting should be increased.

Long (35) stated that the optimum planting rate for corn largely depended on the fertility of the soil and its capacity to deliver water. He also stated that a stand not exceeding 12,000 plants per acre appeared to be best for good corn soils in Tennessee. Parks and Overton (45) found that during relatively dry years a plant population of 12,000 produced a yield comparable to that obtained from lower population.

Jordan et al. (25) reported from a fertilizer-spacing experiment with corn that with 4,000 plants per acre there was a substantial yield increase from the first 60 pound increment of nitrogen and a moderate increase from the second 60 pound increment. With 12,000 plants stand there were substantial yield increases at both the increments of applied nitrogen.

Several experiments (6, 17, 26, 30, 34, 42, 50, 57) have shown that plants growing in fertile soils generally make more efficient use of the available soil moisture than plants growing on soils low in fertility. Bell and Walker (6) stated that for high crop yields, a soil with high moisture supplying capacity was necessary to obtain an optimum response from the fertilizer applied. More fertilizer can be used on soils with a high moisture supplying capacity than on soils with a low moisture supplying capacity. Montgomery and Kiesselbach (42) observed a marked reduction in the transpiration ratio of corn with increasing soil fertility. Hanks and Tanner (17) working with corn and oats in Wisconsin showed that corn yields per inch of water used were on the average 1.4 times greater on the high fertility plots than on the low fertility plots. Krantz (30) reported reduced response to nitrogen for corn under low moisture conditions. Larson, et al. (34) reported large yield increases for corn from nitrogen fertilizers at a high soil moisture but considerably less response at low soil moisture. Similar evidence has been presented by Singleton, et al. (57). Kelley (26), after reviewing the literature on water usage, stated that fertility level had a marked effect on the efficiency of water use by plants. Whenever higher yields were obtained with increased fertilization, there was a corresponding increase in the efficiency of water use.

McGregor (37) found that a shortage of soil moisture

during the growing season can reduce or eliminate fertilizer effects even with adequate plant population and with all other growth factors at an optimum.

The differences in the effective rooting depth of the plants and the capacity of the soil to hold available water in the rooting zone also cause variations in yields on different soil types. The variation in the moisture supplying capacity of the soils was attributed to textural changes by Jamison and Kroth (23).

Russell, et al. (52) found that moisture was first extracted directly underneath the corn plant and then extraction occurred in successive zones laterally from the plant. When most of the available moisture in the upper layer of soil was removed, the pattern was repeated in the next and successive deeper layers as the summer progressed. In agreement with Russell, et al., Foth, et al. (14) found a limited overlap of root systems between the rows in the upper soil and reported a sigmoidal curve representing the root growth through summer. He further stated that the plants might not be effectively utilizing the soil moisture and soil nutrients below a depth of 2 feet. Long (36) reported the depth and penetration of corn roots to be 33, 32, and 46 inches on Lintonia silt loam (1956), Calhoun silt loam (1956), and Almo silt loam (1957), respectively.

Fehrenbacher and Rust (12) suggested that the differences in depth of root penetration and in available soil moisture in

the rooting zone were probably the main factors responsible for differences in the long time average yields on Ringwood, Elliott, Saybrook and Clarence soils of Illinois.

Winters and Simonson (68) stated that the difficulties of root penetration were due to one or more of the following soil characteristics; high bulk density, low porosity, restricted aeration and low fertility.

Gard, et al. (15) explained from soil moisture extraction patterns that lack of easily available moisture apparently lowered the corn yield potential on a silt-pan soil, but a high state of fertility was conducive to efficient water use. Peters (48) explained from an experiment conducted on prepared mixtures of a sand and a clay soil that the uptake of water by corn roots was a function of specific moisture content as well as the moisture tension.

Land and Carreker (33) found under both irrigated and non-irrigated conditions that approximately 85 percent of the corn feed roots were in the top 6 inches and a few roots were below 18 inches in the soil.

Miller and Duley (41) found in corn grown at different fertility levels with varying amounts of moisture during three periods of growth that in all periods minimum moisture gave a greater root growth in proportion to tops than did the maximum moisture even though the actual weight was less during early growth.

The lack of suitable moisture conditions for plant growth that occur from time to time is a focal point of the problems in crop production. Basile (4) defined drought days as any period of deficient rainfall in which vegetation was seriously injured, but this definition was too broad for application. He further defined drought days in a more precise statement, "a period of 20 consecutive days in which there is less than one-half inch of rainfall during the growing season." Van Bavel (66) defined agricultural drought as a condition in which there was insufficient soil moisture available to a crop and "drought-day" as a period of one day during which the drought condition existed.

A drought-day used as a measure of the drought intensity was considered to occur when the available moisture in the soil for the soil-plant relationship in question was exhausted, as estimated from rainfall and evapotranspiration data by a moisture balance method. This measure has considerably more meaning as a measure of drought intensity than rainfall data because of the complete inclusion of relevant climatic, soil and plant factors that brought about drought conditions (65, 66).

Drought variability is due to geographical location, soil properties, and the weather conditions. In the later category the amount and distribution of rainfall and consumptive use of water by crops are of principal significance.

Some workers (21, 58, 59, 63) have reported that July

rainfall is closely correlated with corn yield. One USDA report (63) concluded, "preeminence of Illinois, Indiana, Iowa and Missouri as corn producing states is closely connected with July rainfall." Hodges (21) noted in Kansas that the effect of rainfall and temperature on corn yield was quite variable, and that July droughts affected corn yields adversely.

Engelstad and Doll (11) reported that June and July rainfall accounted for 75 percent of the variation in corn yields in a phosphorus fertility study over a 12-year period at Greenville, Kentucky.

Rust and Odell (54) concluded that more yield variation was associated with weather factors than all other factors studied. Other factors studied included management factors such as the amounts of nitrogen, phosphorus and potassium added, cropping system followed, and liming.

Kincer and Mattice (29) found that the growing crops were influenced by a number of weather elements acting in combination. Mattice (39) divided the corn belt into three parts along state boundaries using those climatic factors giving the highest correlation coefficients as a basis for division.

Fisher (13) developed a method for dividing the growing season into as many periods as desired without unduly complicating the correlation equation. This division made possible a time identification of the weather variables studied. Davis and Pallesen (9) using Fisher's technique found that the total rain-

fall for the season was not significantly correlated with yield.

Hendricks and Scholl (20) studied corn yield estimates for Indiana, Iowa, and Ohio and concluded, "corn yields apparently cannot be predicted much more accurately from weekly weather data than from monthly weather data. However, an analysis based on weekly weather data enables one to determine the seasonal variation of the effects of weather factors more accurately."

Wallace (67) contended that July rainfall was not the dominating factor affecting corn yields in Ohio as it was in many of the other corn belt states. He considered the problems associated with the accurate determination of drought and heat. Robb (49) reported that corn yields were closely correlated with July and August rainfall in northeastern Kansas and that 10-days drought periods were not long enough to damage corn especially if followed immediately by a good rain. A USDA report (62) concluded, "rainfall during the first 10 days of August is a very important factor in determining the probable yield of corn."

Kiesselbach (28) found that corn yield response to drought was dependent upon the stage of growth when the moisture stress occured. Severe early drought resulted in stunted size and delayed silking. Many of the plants failed to silk and some of the tassels were partially or completely sterile. The occurrence of drought following normal growth and fertilization of the ear shoots may cause shortened ears by drying from the tips. The

plants become undernourished if the leaves fire and wilt. The kernels produced on these plants become small or chaffy.

Numerous workers (5, 10, 41, 43, 44, 50, 51) have reported that the moisture stress before silking, during tasseling through silking, and just after silking adversely affects corn yields. Odell (43), by studying first year corn yields from 1903 through 1956 in a corn-corn-oats-red clover rotation concluded that corn yields were influenced most by weather conditions immediately before and during the full tassel stage. He also said that high corn yields can be produced with below normal rainfall from planting time to mid-June, abundant July rainfall, and above average rainfall during the first half of August. Bates and Collier (5) studied the results from four locations in the Blackland area of Texas and reported significant correlation coefficients between corn yields and rainfall from 2 weeks before silking to 2 weeks after silking. Runge and Odell (51) explained up to 67 percent of corn yield variability during the period 1903 through 1956 by precipitation and maximum daily temperatures 50 to 74 days before and 14 to 30 days after full tassel. When the upward trend in yields was included in this analysis, approximately 75 percent of the corn yield variability was explained. Denmead and Shaw (10) found that moisture stress before, at, and after silking reduced the grain yield by 25, 50, and 21 percent, respectively. They suggested that early moisture stress had an indirect effect on grain yields by reducing

the size of the assimilatory surface at the time of ear development, while moisture stress imposed after the ear had emerged had a more direct effect through reducing assimilation of food in the critical period when the daily assimilation rates were high and when most of the assimilate was being used in grain production. Robins and Domingo (50) showed that soil moisture depletion to the wilting percentage for one to two days during the tasseling or pollination period resulted in as much as a 22 percent yield reduction and a deficit period of 6 to 8 days reduced the yield by about 50 percent. Following maturity the depletion of the available soil moisture had no effect upon yield. Parks and Knetsch (44) reported that moisture deficit during tasseling period affected corn yields more than a moisture deficit during other stages of the corn plants growth. They also reported that the response to applied nitrogen increased with decreasing drought intensity. The corn yields increased up to a drought index value of 40 with increasing rates of applied N. At drought index values 49, 59, 74, and 103 the yields increased with increasing rates of applied N up to a level of 175, 150, 125, and 100 pounds, respectively.

Several workers (1, 32, 38, 40, 65) suggested the concept of using daily soil-water balances based on estimates of evapotranspiration for characterizing soil moisture conditions. Although the methods suggested or used by these investigators varied considerably, the common objective was to obtain a

reliable estimate of prevailing soil moisture conditions for large areas inspite of the absence of direct observations of soil-moisture contents.

Blaney and Criddle (7) suggested that monthly evapo-transpiration could be computed by the empirical formula:

$$u = \frac{ktp}{100} = kf \text{---------(1)}$$

Where, u = monthly evapo-transpiration in inches

k = monthly evapo-transpiration coefficient (determined for each crop from experimental data).

t = mean monthly temperature in Fahrenheit

p = monthly percent of day-time hours of year

$f = \frac{tp}{100}$, monthly evapotranspiration factor.

For the entire growing season, the following equation was more convenient, (19), $U = KF$ ----------(2)

Where, U = evapotranspiration for growing season in inches

K = evapotranspiration coefficient for growing season (determined for each crop)

F = sum of monthly evapo-transpiration factor for the period.

Land and Carreker (33) calculated daily evapo-transpiration by using the formula:

$$A = \frac{(B-C) + (D+E) - F}{G}$$

Where, A = evapo-transpiration rate in inches/day

B = available soil moisture in inches at the beginning of the period

C = available soil moisture in inches at the end of the period

C = inches of rainfall during the period

E = inches of irrigation during the period

F = inches of runoff during the period

G = number of days in period.

Several methods have been advanced for potential or maximum evapotranspiration measurement from other climatological data. Even though all of these are still under considerable scrutiny and subject to modification and improvement, the method suggested by Penman (46, 47) appears to be adapted to the greatest variety of conditions, and therefore, seems preferable for use.

Mitscherlich formulated a logarithmic function to explain plant growth. He assumed that a plant should produce a certain maximum yield if all conditions were ideal, but insofar as any essential factor is deficient there is a corresponding decrease in the yield. The mathematical expression attributed to him resulted in a curve that is everywhere concave to the axis representing the nutrient supply (53, pp. 57-62).

Walker[2] defined a prediction equation "------ as the mathematical relationship between a dependent variable and specified independent variables." He also stated that a term was "effective" in a prediction equation "if the ratio of the

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[2]Walker, W. M. Yield and chemical composition of Poa pratensis and Bromus inermis as a function of applied nitrogen, phosphorus, and potassium. Unpub. Ph.D. thesis. Iowa State University, Ames, Iowa. 1961. p. 36.

mean square of the coefficient of the variate to the residual mean square is greater than unity." He justified these on the basis that if the ratio was unity or less, it could be assumed that the variation which was accounted for by this term was part of the same random variation as that which appeared in the residual sum of squares. If either a linear or a quadratic term was effective in a prediction equation then both terms were retained for the prediction of yields.

According to Hader, et al. (16), as long as a variable has an agronomic basis and satisfies an equation model, the coefficients estimated by the method of least squares are the best estimates that are available from data. Walker[3] stated, "this argument can be used as a basis for the retention of statistically insignificant coefficients of variates in a multiple regression equation."

The most logical basis for deleting a variable out of a system lies in the extent to which the yield estimates and their standard errors are actually changed by its omission, (16). When deciding to delete a variable, all terms or at least all terms of a given order involving this variable should be considered as a group.

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[3] Ibid.

CHAPTER III

METHODS AND PROCEDURE

The procedure developed to study this research problem was divided into following four steps:

1. Collection of Data
2. Grouping of Similar Soils
3. Computation of Drought Day Incidence and Drought Index
4. Statistical Methods

Collection of Data

Five hundred and forty-four observations of corn yields available from 1950 through 1961 were collected from several sources. Each observation was accompanied with information on soil tests (pH, K, and P), level of applied fertilizers (N, P_2O_5, and K_2O in pounds per acre), plant population (in thousands of plant per acre), planting date, year and location. The sources of data were: University of Tennessee-Soil Conservation Service cooperative yield study, variety tests, irrigation studies, minimum tillage experiments, fertilizer trials, and the theses of Charles R. Graves, Rural A. Peace, Porter L. Russ and Burgess F. Guinn. Most of the data were from the years 1956 through 1961.

The daily ranfall record for each year (April through September) was obtained for each location (county) from US

Weather Bureau report, (64).

Grouping of Similar Soils

The soils under study were divided into four categories based on an estimate of their expected potential for producing corn. A description of each soil group follows:

Group 1 consists of deep bottomland and a few low terrace soils with weak profile development. Slopes ranged from 0 to 4 percent and erosion from slight to none. They are medium in texture. Most of them occupy a "receiving position" on the landscape i.e., they get some of the water supply lost from the upland soils. This factor may be of considerable importance if the intensity of rainfall is high. The weak profile development and nearly level surface promote deep percolation of water into the soil profile. The available water holding capacity[4] of the top three feet of soil is 7 to 8 inches. In dry seasons roots may easily penetrate to 3 feet or more into the soil.[5]

Group 2 consists of deep colluvial and terrace soils with 2 to 8 percent slopes and slight to moderate erosion. The medium texture of the top ten (10) inch layer and the absence of strong profile development in the B horizon favor high infiltration

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[4]Available Water Holding Capacity mentioned in each soil group was calculated from the unpublished data of T. J. Longwell, University of Tennessee, Knoxville, Tennessee. The calculation is shown in Appendix A.

[5]The rooting depth mentioned in each soil group is based on experiences with field observations of the experimenters.

capacity. The available water holding capacity of the top three feet of soil is 5.0 to 6.0 inches. In dry seasons roots may penetrate 2 to 3 feet into the soil.

Group 3 consists of moderately deep, undulating upland and high terrace soils with 2 to 12 percent slopes and slight to moderate erosion. The 0 inch to 7 inch silt loam texture at the top is followed by strongly developed B horizon. The available water holding capacity of the top three feet of soil is 4.5 to 5.0 inches. In dry seasons roots may penetrate greater than 2 feet into the soil.

Group 4 consists of upland and high terrace soils. These soils occupy a sloping to hilly position on the landscape with 12 to 25 percent slopes and slight to moderate erosion. They have a very strong profile development in the B horizon. Slope gradient and the degree of erosion may be the limiting factors for corn production on this group. The available water holding capacity of the top three feet of soil is 4.0 to 4.5 inches. In dry seasons roots may penetrate greater than 2 feet into the soil.

On the basis of the criteria used the groups 1 through 4 were considered as "highest", "high", "medium", and "low", respectively in expected potential for producing corn. The soils in these groups are recorded in Appendix B.

Computation of Drought Day Incidence and Drought Index

The computation of drought day incidence required the use of three factors: daily rainfall, daily evapotranspiration rates, and moisture base (amount of available water in the root zone) of each soil group. Since the information was available only for the first two factors and not for the third one, it was decided to compute the drought day incidence at each of the locations for 1, 2, 3, 4, and 6 inch moisture bases. The purpose of computing the drought day incidence at 5 levels of moisture base was to find out an appropriate moisture base whose drought values could be used in the regression analysis. To do this, it was decided to run the general regression analysis for the drought values of each moisture base within each soil group by holding all the other factors constant. The drought value which would give the highest R^2 within each soil group was the criterion for selection of the appropriate moisture base.

The average daily evapotranspiration rates (Appendix C) used were calculated by Penman equation (Appendix D) for selected locations applicable to various areas of the Tennessee valley.[6] The evapotranspiration rates of East, Middle, and West Tennessee were used in drought day computation for locations in East, Middle, and West Tennessee, respectively.

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[6]The Occurrence of Drought in the Tennessee Valley. TVA, Knoxville, Tennessee. T58-2AE, June 1958. p. 7.

The computation of drought day incidence by the moisture balance method was done by the addition of daily rainfall and subtraction of daily losses due to evapotranspiration. The procedure is stated in terms of a simple equation (Appendix E).

For this computation the assumptions were that the soils were at field capacity on March 31 of every year at each location, the moisture level never exceeded the base amount (moisture base), the moisture level was never less than zero, and excess moisture lost to the crop either by run off or by percolation. A zero level of available moisture was considered as a critical level in the moisture supply and each day in which this condition existed was considered a "drought day". Each successive day was counted as an additional drought day until a rainfall occurred of sufficient magnitude to be greater than the rate of daily evapotranspiration. A sample computation of drought day is shown in Appendix F.

Since the occurrence of drought days in the different maturity stages of corn plants affect corn yields differently, it was decided to assign weights to them by computing the drought index values. The drought index values were computed for the moisture bases 1 inch through 4 inches from the equation (Appendix G) developed by Parks and Knetsch (44). This equation (Appendix G) was used to compute the drought index with the assumption that the values obtained would fit the data best in the regression analysis. The drought index was not computed

for 6 inch moisture base as the drought incidence for this base was negligible and it was deleted from further study.

Statistical Methods

With the large number of yield observations available and the availability of the estimates of many of the factors affecting corn production, regression analysis was an appropriate statistical technique for measuring the relationship between selected soil, climate and management factors expressed as independent variables and corn grain yields.

Multiple regression techniques used in this thesis will, in general, follow the procedures of multiple regression analysis discussed by several authors (2, 27, 61). On the basis of past agronomic research, nine production factors were selected as independent variables and the mathematical relationship between selected variables and observed corn yields was measured. They were: pH, K soil test, K applied, P soil test, P applied, N in pounds per acre, plant population in thousand of plants per acre, soil group and drought index. Yield of ear corn in bushels per acre was the dependent variable.

The soil groups were coded as follows: "-3" for "highest", "-1" for "high", "+1" for "medium", and "+3" for "low" in expected potential for producing corn. This is a qualitative coding and if the different soil groups exert a significant effect upon corn yields and this method of coding is appropriate, the effect

should be indicated by the statistical significance of the regression coefficient of the soil group term.

Every variable mentioned previously was not used in each of the euqations. Five different equations were selected based on five sets of observations. These five sets of observations were: (1) all 544 observations combined together; (2) all of the 221 observation on soil group 1; (3) all of the 127 observations on soil group 2; (4) all of the 152 observations on soil group 3; and (5) all of the 44 observations on soil group 4.

In each of the five sets of observations, four general regression equations, one corresponding to the drought index values for each of the four moisture bases, were obtained. The drought index values that gave the highest R^2 (coefficient of multiple determination) was considered to be the best fit for the data.

All data were punched on IBM cards and the regression analyses were computed on an IBM 1620 Electronic Digital Computer at the University of Tennessee Computing Center.

The program used to analyse the data on the computer is a stepwise regression analysis program called STRAP, developed by A. R. Colville and L. S. Holmes. This program was used to determine the relationship between selected independent and dependent variables. The independent variables are added to the regression equation one at a time. A given variable is entered into the regression equation if the variance reduction obtained

by adding that variable is significant at a specified F level.

For each step in the development of the regression equation, the following values are given:

1. The error of estimate of the dependent variable.
2. The F ratio of the variable added to the equation at that step.
3. The pure constant term that is, the intercept.
4. The regression coefficients of each of the variables in the equation.
5. The standard errors of the regression coefficients.
6. The coefficient of multiple determination (R^2).

It has been theorized and shown that crop yields increase at a decreasing rate until a maximum yield is reached, and they then decrease with increasing increments of a specific management factor (18); therefore, a quadratic function with selected linear x linear cross product terms was chosen as an appropriate regression model. Quadratic terms of all the independent variables were used in each of the equations.

According to Walker "....selection of terms to be used in a prediction equation is determined by the model and the probability level required for significance."[7]

After the general regression was computed for each set of observations, those variables which were not significant at a

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[7]Walker, op. cit., p. 25.

probability level equal to or less than 0.20 were deleted and a new regression function was computed with the remaining variables. This process was repeated until at least one effect of each remaining variable was significant at a probability level equal to or less than 0.20. If either a linear or a quadratic effect was significant, then both the linear and the quadratic terms were retained in the prediction equation. When a linear x linear effect was significant, each of the linear terms and their quadratic terms were also retained. The resultant equation in each instance was termed an "effective" equation.

"Specific" equations were used to predict corn yields. Each "specific" equation contained two selected significant independent variables with a quadratic term for each, plus their linear x linear interaction term. Production surfaces were used to illustrate the effect of selected factors on corn yields.

The algebraic signs of the regression coefficients in a prediction equation indicate the direction of the regression line with respect to the dependent variable as increments of the independent variable are changed. When fitting an equation model of the form $Y = a + b_1x + b_2x^2$ to agronomic data, the regression coefficient of the linear effect is expected to be positive and the coefficient of the quadratic effect is expected to be negative.

The determination of relationships between various production factors and corn yield may help in selecting the level of specified factors required for maximum corn yields and for determining the combination of management factors for the most profitable yield.

CHAPTER IV

RESULTS AND DISCUSSION

Four general regression equations, one corresponding to each moisture base (1", 2", 3", and 4", respectively), were computed for each of the five sets of observations with several production factors expressed as independent variables. Table 1 shows the R^2 values with four moisture bases within each of the five sets of observations. In the first set of observations, there was slight difference between the R^2 value for the 2 inch moisture base and the R^2 values of 1, 3, and 4 inch moisture bases, but there were no appreciable differences among the R^2 values of moisture bases 1, 3, and 4 inches within this set. A similar trend of R^2 values was found in the second set of observations. In the third and fourth set of observations there were no marked differences among the R^2 values of moisture bases 1 through 4 inches within each of the two sets. In the fifth set of observations, there were slight differences between the R^2 value of moisture base 1" and the R^2 values of 2, 3, and 4 inch moisture bases, but variation between the R^2 values of 2, 3, and 4 inch moisture bases within this set was not appreciable. A perusal of rainfall records and a very limited occurrence of drought days at the selected locations (counties) under study indicated that the amount and distribution of rainfall during the period 1956 through 1961 were probably adequate. Therefore,

Table 1.--R^2 values with four moisture bases within each of the five sets of observations.

Sets of observations	Moisture base			
	1"	2"	3"	4"
1. All observations combined	0.535	0.491	0.543	0.565
2. All of the observations on soil group 1	0.602	0.554	0.594	0.592
3. All of the observations on soil group 2	0.588	0.577	0.572	0.565
4. All of the observations on soil group 3	0.827	0.827	0.820	0.809
5. All of the observations on soil group 4	0.702	0.764	0.748	0.749

all the four moisture bases within each set of observations had almost the same R^2 values.

There were considerable differences in R^2 values between soil groups. In general, the R^2 values of soil groups 3 and 4 were higher than the R^2 values of soil groups 1 and 2 at all selected moisture bases. The fact that the production factors selected account for more of the variation in corn yields on soil groups 3 and 4 than on soil groups 1 and 2 indicates that these factors were more limiting on the medium and low potential soils.

It was initially decided that the drought index level which would give the highest R^2 value would be considered as the appropriate one for use in the regression equations. Therefore, general regression equations selected for 1, 2, 3, 4, and 5 sets of observations were those obtained within each set from moisture base 4", 1", 1", 1", and 2", respectively, because they gave the highest R^2 value.

"Effective" prediction equations were developed from each of the five selected general regression equations. Variables were deleted from each of the general regression equations if they were not significant at a probability level equal to or less than 0.20, therefore, no two effective prediction equations necessarily have the same set of variables or terms.

All Observations Combined

Five hundred and forty-four observations using nine independent variables with a quadratic effect for each variable,

plus eleven linear x linear interactions were included in the analysis of variance. This analysis of variance is presented in Table 2.

The interaction N·Pop, Ka·DI, and the linear effect of SG were the first, second, and third most significant factors, respectively, in explaining yield variation. The linear effects of Pop, DI, pH, Pa, and Ks were each highly significant.[8] The linear effects of N and Ka were significant at 0.05 and 0.20 probability levels, respectively. The quadratic effects of Ka, Pop, and N were significant at 0.01, 0.05, and 0.20 probability levels, respectively. The interactions pH·Pa and Ks·Ka were each highly significant and the N·Pa and Pa·DI interactions were each significant in accounting for variations in corn yields. This equation:

$$\hat{Y} = 12.171 - 3.589pH + 0.184\ Ps + 0.046Ks + 0.099N + 1.037Pa + 0.162Ka + 4.283Pop - 2.829SG - 1.058DI + 0.0002Ps^2 + 1.268pH^2 + 0.066SG^2 + 0.00003Ks^2 - 0.0001N^2 + 0.0003Pa^2 - 0.0004Ka^2 - 0.029Pop^2 - 0.003DI^2 - 0.007N·Pop + 0.0002N·Pa - 0.0009N·Ps - 0.156pH·Pa - 0.23pH·Ps + 0.0005N·DI + 0.008Pa·DI + 0.005Ka·DI - 0.001Ks·Ka + 0.002Ps·Pa - 0.006N·SG \quad \text{----------(1a)}$$

has a R^2 of 0.564. The legend for the terms used in the various equations is presented in Table 3.

The variables were deleted which were not significant at

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[8] Hereafter the term "highly significant" will refer to significance at a probability level equal to or less than 0.01, and "significant" will refer to a probability level equal to or less than 0.05.

Table 2.--Analysis of variance of corn yield on Tennessee soils (equation 1a).

Source of variation	Degrees of freedom		F
Total (N = 544)			
Mean	1		
Regression	29		
Linear		9	
N		1	6.13*
Pa		1	19.88**
Ka		1	1.98++
Ps		1	0.09
Ks		1	17.23**
pH		1	21.55**
Pop		1	43.30**
DI		1	34.70**
SG		1	47.62**
Quadratic		9	
N^2		1	2.24++
Pa^2		1	0.24
Ka^2		1	23.41**
Ps^2		1	0.15
Ks^2		1	0.65
pH^2		1	0.29
Pop^2		1	4.47*
DI^2		1	1.24
SG^2		1	0.05

Table 2.--(Continued)

Source of variation	Degrees of freedom		F
Interaction	11		
N•Pop		1	112.71**
N•Pa		1	5.41*
N•Ps		1	1.13
Pa•Ps		1	0.24
Ka•Ks		1	23.57**
pH•Pa		1	36.98**
pH•Ps		1	0.03
N•DI		1	0.09
Pa•DI		1	5.64*
Ka•DI		1	56.17**
N•SG		1	0.92
Residual	514		

**In this and/or future tables, the double asterisk will indicate a probability level equal to or less than 0.01.

*In this and/or future tables, the single asterisk will indicate a probability level equal to or less than 0.05.

+In this and/or future tables, the single plus (+) sign will indicate a probability level equal to or less than 0.10.

++In this and/or future tables, the double plus (++) sign will indicate a probability level equal to or less than 0.20.

Table 3.--Key to abbreviations of terms used in the various regression equations.

Abbreviated term	Definition of terms
$\hat{Y}$	Total predicted corn yield in bushels per acre
Pop	Plant population in thousands of corn plants per acre
N	Pounds of elemental nitrogen applied per acre
Pa	Pounds of P_2O_5 applied per acre. In specific prediction equations, it has been expressed as pounds of elemental phosphorus applied per acre
Ka	Pounds of K_2O applied per acre. In specific prediction equations, it has been expressed as pounds of elemental potassium applied per acre
Ps	Pounds of available phosphorus per acre as determined by soil test
Ks	Pounds of exchangeable potassium per acre as determined by soil test
pH	Soil pH
SG	Soil group
DI	Drought index as determined by the equation (Appendix G) is expressed in numerical values. Greater the positive numerical value, greater the moisture stress
A·B*	Linear X linear interaction term for any two specified variables; A and B

*All interactions will be shown by separating the two linear factors with a dot, for example N·Pop.

a probability level equal to or less than 0.20. This procedure was repeated until at least one effect of each of the remaining variables was significant at the specified probability level. At this point the analysis of variance contained seven linear variables and their quadratic effects, plus six linear x linear interaction terms. This analysis of variance showing source of variation, degrees of freedom, and F ratios is presented in Table 4. The N·Pop interaction and the quadratic effect of Pop were the first and second most significant factors in explaining yield variations. The linear effects of DI, pH, N, Ks, Pop, and Pa were each highly significant. The linear effect of Ka was significant at 0.20 level of probability. The quadratic effect of Ka was highly significant and the quadratic effect of N was significant at 0.20 probability level. The pH·Pa, Pa·DI and Ks·Ka interactions were each highly significant and the interactions Ka·DI and N·Pa were significant at 0.05 and 0.10 levels of probability, respectively. This "effective" prediction equation:

$$\hat{Y} = -3.551 - 0.207pH + 0.041Ks + 0.129N + 1.175Pa + 0.157Ka + 4.621Pop - 1.037DI + 1.05pH^2 + 0.00004Ks^2 - 0.00002N^2 + 0.0003Pa^2 - 0.0004Ka^2 - 0.031Pop^2 - 0.002DI^2 - 9.007N \cdot Pop + 0.0002N \cdot Pa + 0.009Pa \cdot DI + 0.004Ka \cdot DI - 0.00099Ks \cdot Ka - 0.172pH \cdot Pa \quad (1b)$$

has a R^2 of 0.531.

Table 5 shows the predicted corn yields obtained with varying levels of applied N and plant population from the specific equation:

$$\hat{Y} = 36.642 + 0.191N + 1.442Pop - 0.0002N^2 - 0.031Pop^2 - 0.003N \cdot Pop \quad (1c)$$

Table 4.--Analysis of variance of corn yield on Tennessee soils (equation 1b).

Source of variation	Degrees of freedom		F
Total (N = 544)			
Mean	1		
Regression	20		
Linear		7	
N		1	16.88**
Pa		1	9.23**
Ka		1	2.12++
Ks		1	14.25**
pH		1	20.93**
Pop		1	9.42**
DI		1	41.05**
Quadratic		7	
N^2		1	2.31++
Pa^2		1	0.39
Ka^2		1	13.29**
Ks^2		1	0.91
pH^2		1	0.18
Pop^2		1	63.56**
DI^2		1	0.48
Interaction		6	
N·Pop		1	112.71**
N·Pa		1	3.67+
Ka·Ks		1	22.07**
pH·Pa		1	44.92**
Pa·DI		1	44.40**
Ka·DI		1	5.82*
Residual	523		

Table 5.--Predicted corn yields as a function of plant population and applied N (equation 1c).

Population (M Plants/A)	N (Lbs./A) 0	30	60	90	120	150	Ave.
4	41.91	47.10	51.93	56.40	60.51	64.26	53.68
8	46.19	51.02	55.49	59.60	63.35	66.74	57.06
12	49.48	53.95	58.06	61.80	65.20	68.23	59.45
16	51.77	55.88	59.63	63.02	66.05	68.72	60.85
20	53.08	56.83	60.22	63.25	65.92	68.23	61.25
24	53.39	56.78	59.81	62.48	64.79	66.74	60.66
Ave.	49.30	53.59	57.52	61.09	64.30	67.15	58.82

which has a R^2 of 0.319. Figure 1 is a production surface illustrating these predicted yields. The highest[9] predicted yield (68.72 bu./A) was obtained with 150 pounds of N and 16,000 population;[10] whereas, the lowest predicted yield (41.91 bu./A) was obtained with no applied N and 4,000 plants per acre. Within the range of the data[11] studied, the predicted yields at all rates of applied N increased with increasing population except at a population of 24,000 plants per acre, and the predicted yields at all levels of population increased with increasing rates of applied N. Beyond a population of 12,000 plants per acre, an increase in the predicted yield was almost negligible and it decreased at a population of 24,000 plants per acre. This supports a view reported by Long (35) that a stand not exceeding 12,000 plants per acre appears to be the appropriate one for good corn on Tennessee soils in general.

Predicted yields as a function of drought index and applied P were obtained from the specific equation:

$$\hat{Y} = 78.891 + 0.687Pa - 0.873DI - 0.0026Pa^2 + 0.003DI^2 + 0.01Pa \cdot DI \text{----------(1d)}$$

which has a R^2 of 0.298. These yields are presented in Table 6.

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[9]Hereafter the terms "highest" and "lowest" in reference to yield means the highest and lowest predicted yields, respectively, within the range of the data used for the calculations.

[10]Hereafter the term "population" means the number of plants per acre.

[11]Hereafter the term "range of data" indicates the range of both the dependent and independent variables within a particular set of observations.

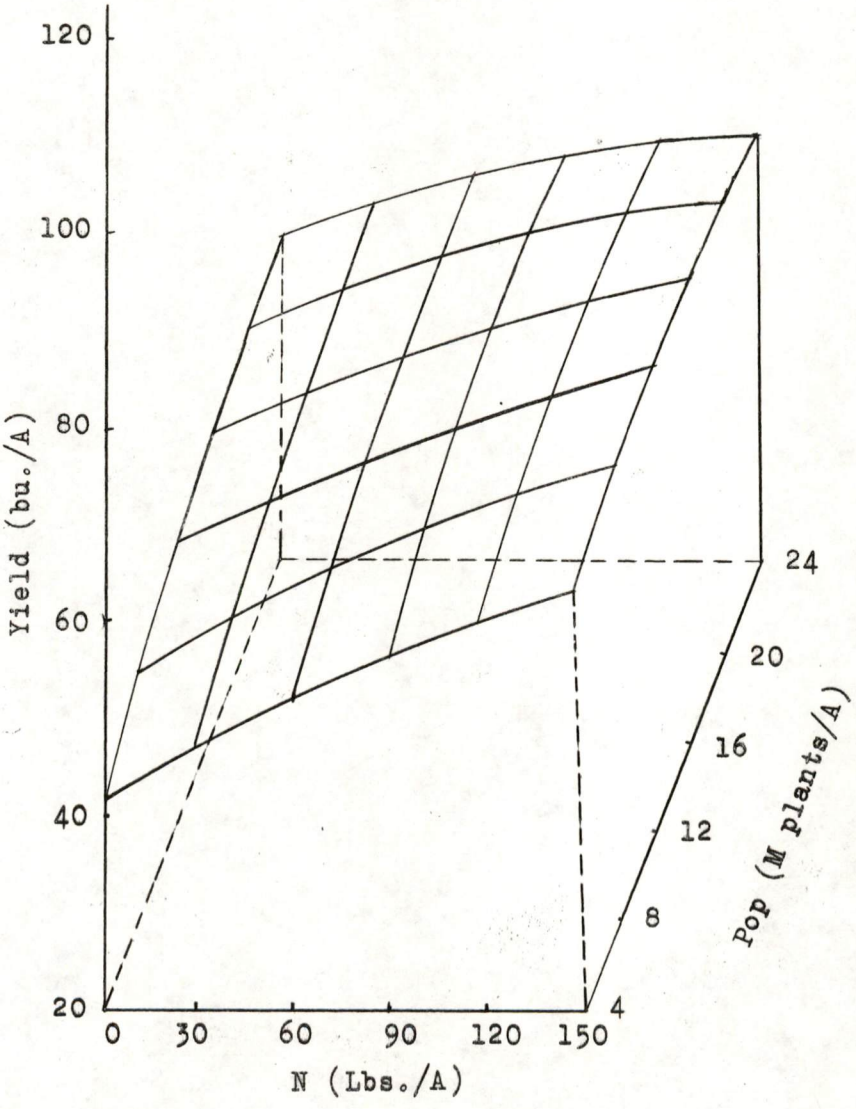


Figure 1.--Predicted corn production surface as a function of applied N and plant population on Tennessee soils (equation 1c).

Table 6.--Predicted corn yields as a function of drought index and applied P (equation 1d).

Drought index	Pa (Lbs./A)						
	0	5	10	15	20	25	Ave.
-5	83.33	86.45	89.44	92.30	95.03	97.63	90.69
10	70.46	74.33	78.07	81.68	85.16	88.51	79.70
25	58.94	63.56	68.05	72.41	76.64	80.74	70.05
40	48.77	54.14	59.38	64.49	69.47	74.32	61.76
55	39.95	46.07	52.06	57.92	63.65	69.25	54.81
70	32.48	39.35	46.09	52.70	59.18	65.53	49.22
Ave.	55.65	60.65	65.51	70.25	74.85	79.33	67.70

The production surface illustrating these yields is in Figure 2. Within the range of the data studied, the highest yield (97.63 bu./A) was obtained with the highest amount of applied P and the lowest level of drought index; whereas, the lowest yield (32.48 bu./A) was obtained with the lowest amount of applied P and the highest level of drought index.

The predicted yields decreased at all rates of applied P with increasing drought index values, but the predicted yields increased at all drought index values with increasing rates of applied P. Therefore, it seems that the effect of drought on corn yields may be modified with increasing rates of P application. This may be due to variations in nutrient uptake and efficiency of water utilization by plants under conditions of varying moisture stresses and applied P.

Table 7 shows the predicted yields as a function of applied P and pH obtained from the specific equation:

$$\hat{Y} = -107.87 + 48.439pH + 2.094Pa - 3.214pH^2 - 0.003Pa^2 - 0.190pH \cdot Pa \text{----------(1e)}$$

which has a R^2 of 0.294. The production surface presented in Figure 3 illustrates the effect of pH and Pa on predicted yields. The highest yield (90.94 bu./A) was obtained with 25 pounds of applied P and a pH of 7.0; whereas, the lowest yield (53.97 bu./A) was obtained with no applied P and a pH of 5.0. The predicted yields at all levels of pH increased with increasing rates of applied P; and similarly, the predicted yields at all rates of applied P increased with increasing pH.

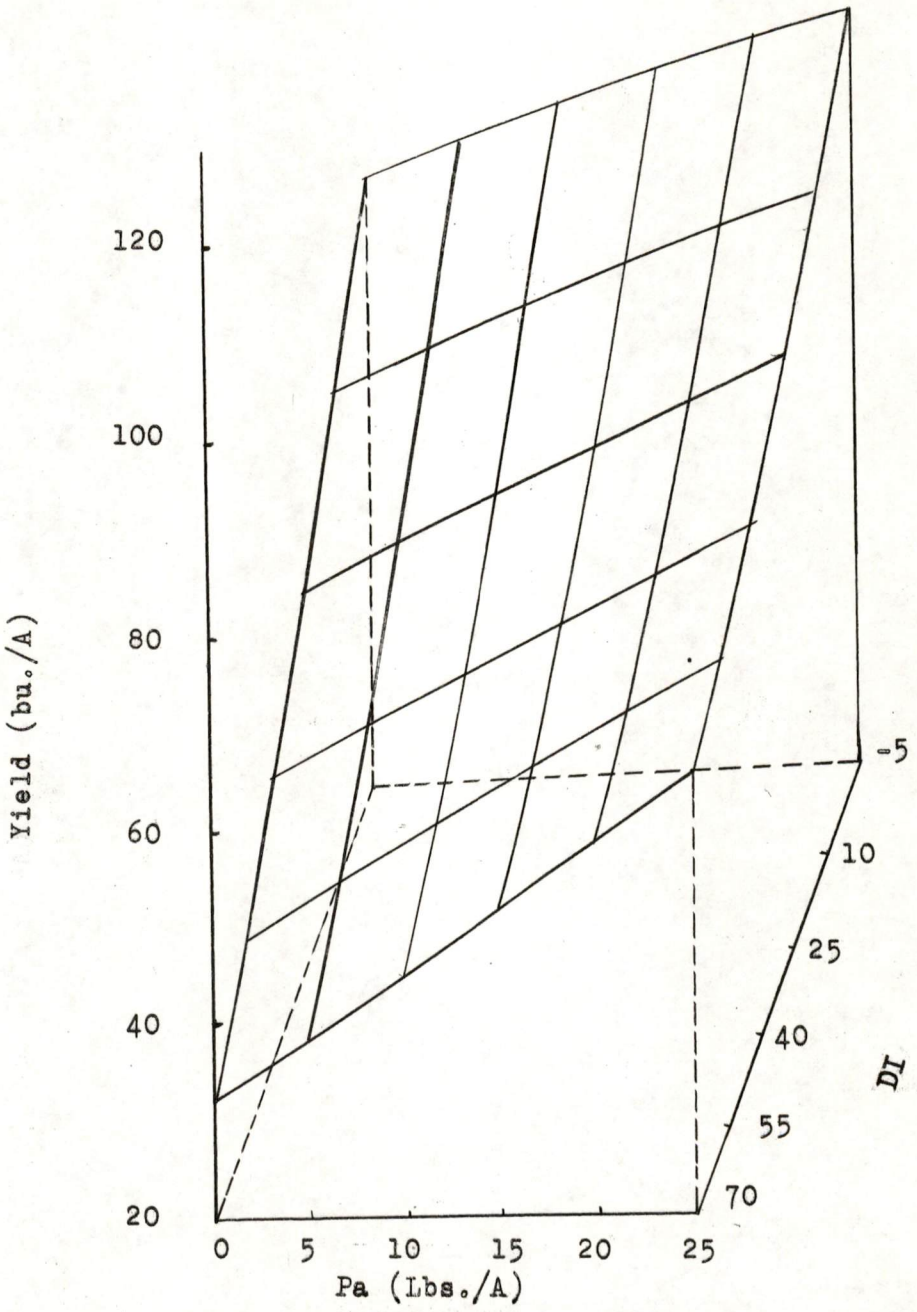


Figure 2.--Predicted corn production surface as a function of drought index and applied P on Tennessee soils (equation 1d).

Table 7.--Predicted corn yields as a function of applied P and pH (equation 1e).

Pa (Lbs./A)	pH 5.0	5.5	6.0	6.5	7.0	Ave.
0	53.97	61.32	67.06	71.19	73.71	65.45
5	59.62	66.49	71.75	75.41	77.46	70.14
10	65.11	71.51	76.30	79.48	81.05	74.67
15	70.46	76.38	80.69	83.40	84.50	79.08
20	75.65	81.10	84.94	87.17	87.79	83.33
25	80.70	85.67	89.03	90.79	90.94	87.43
Ave.	67.58	73.74	78.29	81.24	82.57	76.68

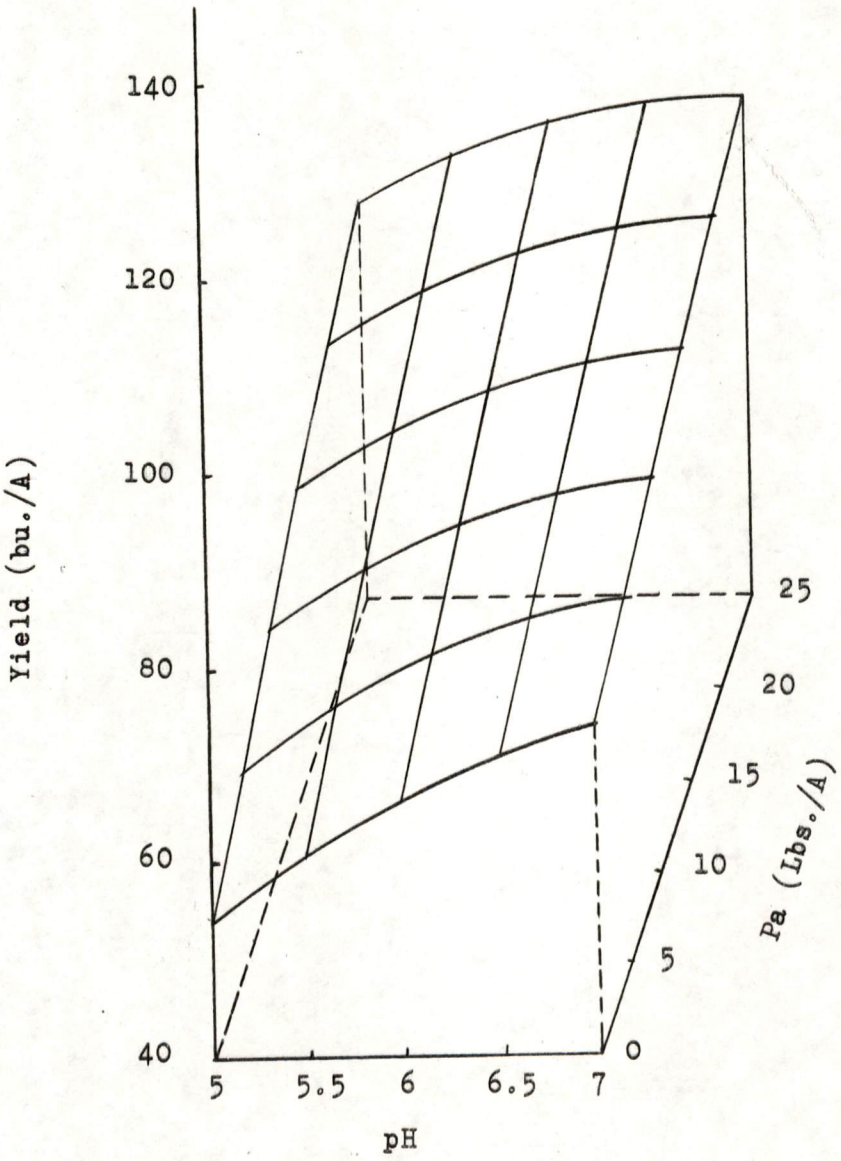


Figure 3.--Predicted corn production surface as a function of applied P and pH on Tennessee soils (equation 1e).

When the pH increased from 6.5 to 7.0, the increase in the predicted yields was almost negligible above the 10 pound level of applied P. This may be due to the influence of different pH levels on the availability of different nutrients to the plants, and is in agreement with a result reported by Salter and Barnes (55) on Canfield silt loam soil of Ohio.

Table 8 shows the predicted yields as a function of applied K and soil K obtained from the specific equation:

$$\hat{Y} = 68.611 + 0.035Ks + 0.418Ka - 0.000006Ks^2 - 0.0006Ka^2 - 0.00024Ks \cdot Ka \quad \text{----------(1f)}$$

which has a R^2 of 0.308. A production surface illustrating these predicted yields is presented in Figure 4. Within the range of the data studied the predicted yields at all rates of applied K increased slowly with increasing levels of soil K, but the predicted yields at all levels of soil K increased rapidly with increasing rates of applied K. This would indicate that under conditions of this study several pounds of exchangeable K as measured by soil tests are required to obtain almost the same corn yield response. It is probable that one or both of these factors are closely correlated with some other factors (application of K in bands or in rows, etc.) affecting corn yields. Therefore, it seems that the effect of increasing rates of applied K on corn yields may be masked with increasing soil K. The highest predicted yield (107.20 bu./A) was obtained with 300 pounds of soil K and 100 pounds of applied K; whereas, the lowest predicted

Table 8.--Predicted corn yields as a function of applied K and soil K (equation 1f).

Ka (Lbs./A)	Ks (Lbs./A) 50	100	150	200	250	300	Ave.
0	70.37	72.08	73.75	75.40	77.01	78.60	74.53
20	78.25	79.72	81.15	82.56	83.93	85.28	81.81
40	85.65	86.88	88.07	89.24	90.37	91.48	88.61
60	92.57	93.56	94.51	95.44	96.33	97.20	94.93
80	99.01	99.76	100.47	101.16	101.81	102.44	100.77
100	104.97	105.48	105.95	106.40	106.81	107.20	106.13
Ave.	88.47	89.58	90.65	91.70	92.71	93.70	91.03

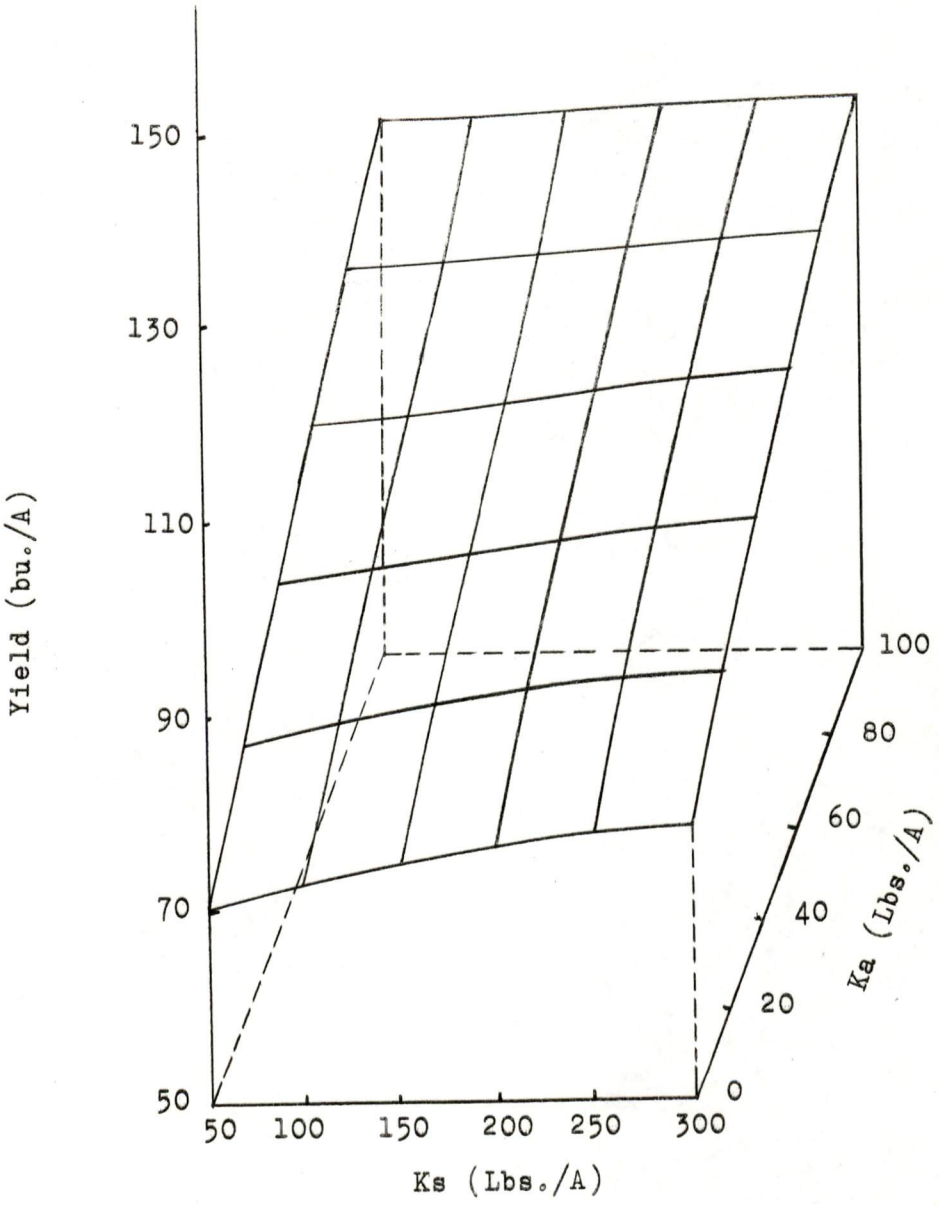


Figure 4.--Predicted corn production surface as a function of applied K and soil K on Tennessee soils (equation 1f).

yield (70.37 bu./A) was obtained with no applied K and 50 pounds of soil K.

Figure 4 illustrating the effect of soil K and applied K on corn yields shows almost no interaction, but the analysis of variance presented in Table 4 shows that the effect of interaction Ks.Ka is highly significant. Figure 4 not showing interaction may be due to use of the specific equation (1f) for predicting corn yields which contained only the linear, quadratic, and interaction terms of soil and applied K, and ignored the other factors significantly affecting corn yields. It seems that the specific equation (1f) may not be adequate for predicting corn yields, and for a more appropriate prediction it may be desirable that at least all the factors which significantly affect corn yields be included in the prediction equation.

Predicted corn yields as a function of drought index and applied K were obtained from the specific equation:

$$\hat{Y} = 80.471 + 0.341Ka - 0.954DI - 0.0006Ka^2 + 0.003DI^2 + 0.01Ka \cdot DI \text{----(1g)}$$

which has a R^2 of 0.285. These yields are presented in Table 9. The production surface illustrating the effect of applied K and drought index on predicted yields is shown in Figure 5. The predicted yields decreased at all levels except at 80 and 100 pound levels of applied K with increasing drought index values, but the predicted yields increased at all values of drought index with increasing rates of applied K. At 80 pound level of

Table 9.--Predicted corn yields as a function of drought index and applied K (equation 1g).

Drought index	Ka (lbs./A)						
	0	20	40	60	80	100	Ave.
-5	85.31	90.89	95.99	100.61	104.75	108.41	97.66
10	71.23	79.81	87.91	95.53	102.67	109.33	91.08
25	58.49	70.07	81.17	91.79	101.93	111.59	85.84
40	47.11	61.69	75.79	89.41	102.55	115.21	81.96
55	37.07	54.65	71.75	88.37	104.51	120.17	79.42
70	28.39	68.97	69.07	88.69	107.83	126.49	78.24
Ave.	54.60	67.68	80.28	92.40	104.04	115.20	85.70

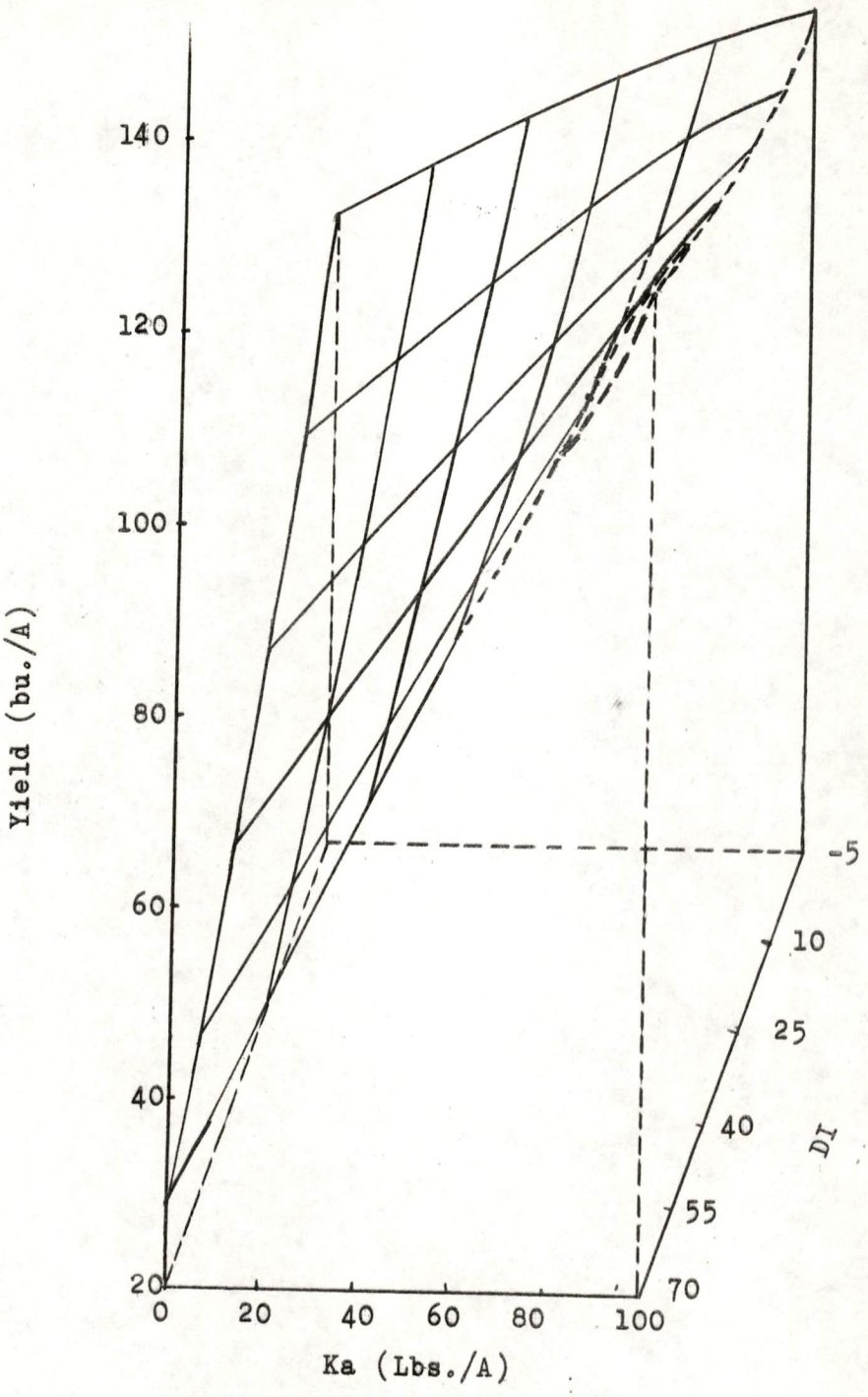


Figure 5.--Predicted corn production surface as a function of applied K and drought index on Tennessee soils (equation 1g).

applied K the predicted yields increased with an increase in drought index values beyond 25, and at 100 pound level of applied K the predicted yields increased with increasing drought index values, which is normally not expected. This may be because most of the corn yield observations under study are associated with high rates of applied N and P, and high levels of plant populations. Therefore, it seems that the increase in predicted yields with increasing drought index values can not be only due to high rate of applied K but this may be due to the combined effects of other factors such as high rates of applied N and P, high levels of plant population, etc. Within the range of the data studied, the highest yield (126.49 bu./A) was obtained with 100 pounds of applied K and a drought index level of 70; whereas, the lowest yield (28.39 bu./A) was obtained with no applied K and a drought index level of 70.

Predicted corn yields as a function of drought index and applied N were obtained from the specific equation:

$$\hat{Y} = 83.969 + 0.193N - 0.784DI - 0.0002N^2 + 0.005DI^2 - 0.0005N \cdot DI \quad \text{-------(1h)}$$

which has a R^2 of 0.208. These yields are presented in Table 10. A production surface illustrating these predicted yields is presented in Figure 6. The predicted yields at all rates of applied N decreased with increasing drought index values; but the predicted yields at all values of drought index increased with increasing rates of applied N. This is in agreement with

Table 10.--Predicted corn yields as a function of drought index and applied N (equation 1h).

Drought index	N (Lbs./A)						Ave.
	0	30	60	90	120	150	
-5	88.01	93.69	99.02	103.98	108.59	112.83	101.02
10	76.62	82.08	87.18	91.92	96.30	100.32	89.07
25	67.49	72.72	77.60	82.11	86.27	90.06	79.38
40	60.60	65.61	70.26	74.55	78.48	82.05	71.93
55	55.97	60.75	65.18	69.24	72.95	76.29	66.73
70	53.58	58.14	62.34	66.18	69.66	72.78	63.78
Ave.	67.05	72.17	76.93	81.33	85.38	89.06	78.65

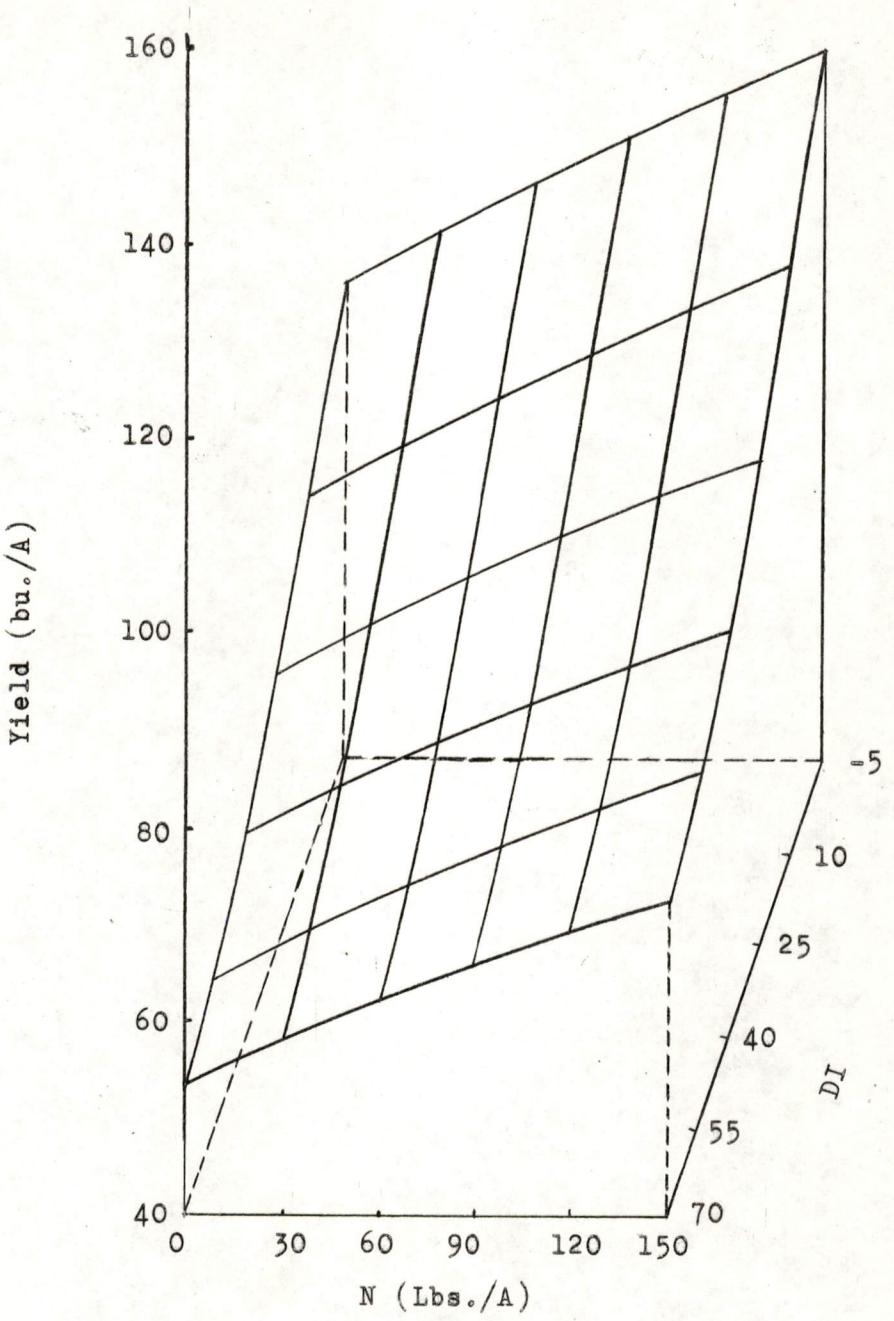


Figure 6.--Predicted corn production surface as a function of drought index and applied N on Tennessee soils (equation 1h).

the findings of Parks and Knetsch (44).

The highest predicted yield (112.83 bu./A) was obtained with 150 pounds of applied N and drought index value of -5; whereas, the lowest predicted yield (53.58 bu./A) was obtained with no applied N and drought index value of 70.

Table 11 shows predicted corn yields as a function of plant population and pH obtained from the specific equation:

$$\hat{Y} = -138.926 + 40.094pH + 17.058Pop - 1.615pH^2 - 0.039Pop^2 - 2.004pH \cdot Pop \quad (1i)$$

which has a R^2 of 0.299. The production surface illustrating these predicted yields is shown in Figure 7. The highest predicted yield (167.61 bu./A) was obtained with 24,000 population and 5.0 pH; whereas, the lowest predicted yield (48.69 bu./A) was obtained with 4,000 population and 5.0 pH. At 4,000 and 8,000 populations the predicted yields increased with increasing pH but the predicted yields decreased with increasing pH beyond a 8,000 population. Apparently, the beneficial effect of an increasing pH is modified by an increase in plant population. It is probable that one or both of these factors are closely correlated with some other factors affecting corn yields.

All Observations on Soil Group 1

The observations in this set are all on the soils with a "highest" expected potential for producing corn. Two hundred and twenty-one observations using eight independent variables

Table 11.--Predicted corn yields as a function of plant population and pH (equation 1i).

Population (M Plants/A)	pH					
	5.0	5.5	6.0	6.5	7.0	Ave.
4	48.69	56.25	63.01	68.95	74.09	62.19
8	74.97	78.52	81.27	83.21	84.34	80.46
12	100.00	99.55	98.29	96.21	93.34	97.47
16	123.79	119.32	114.05	107.97	101.09	113.24
20	146.32	137.85	128.57	118.49	107.59	127.76
24	167.61	155.13	141.85	127.75	112.85	141.03
Ave.	110.23	107.77	104.50	100.43	95.55	103.69

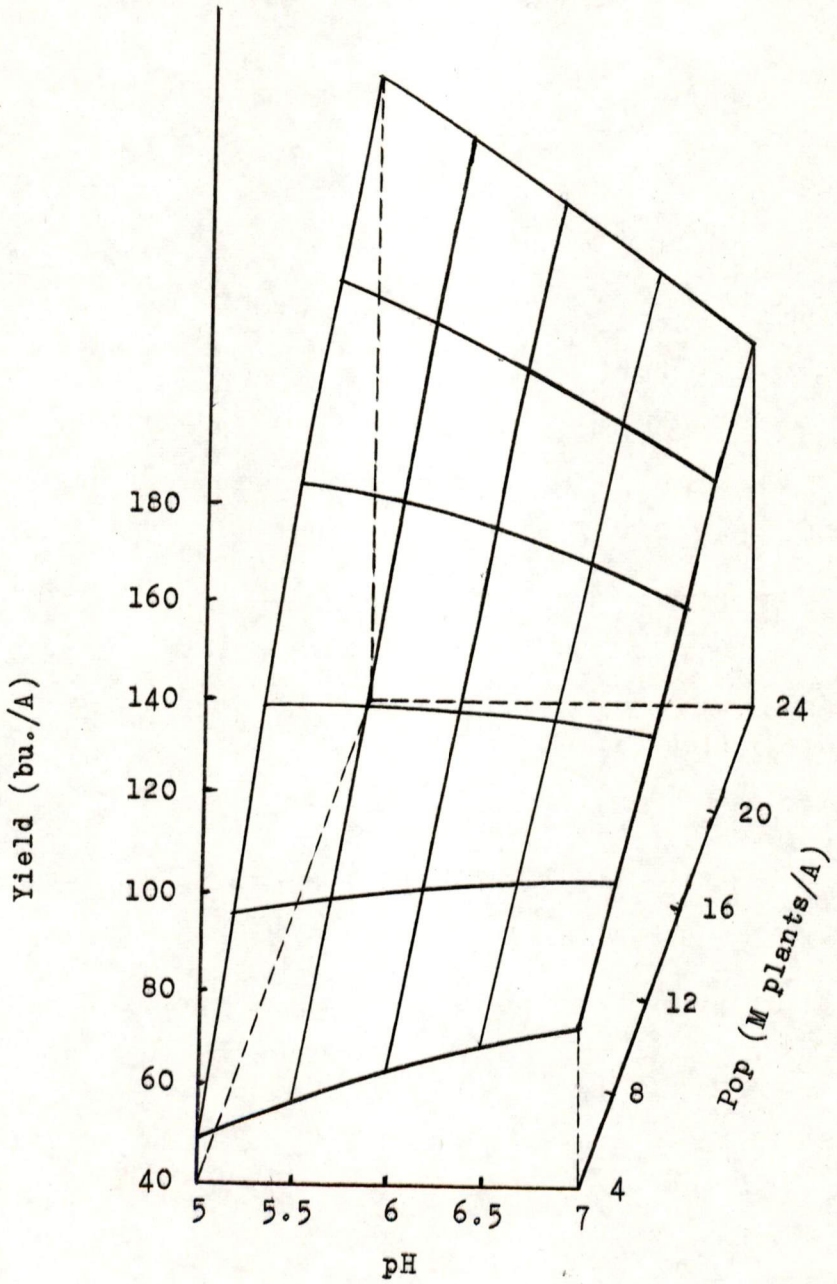


Figure 7.--Predicted corn production surface as a function of plant population and pH on Tennessee soils (equation 1i).

with a quadratic effect for each variable, plus ten linear x linear interactions were included in the analysis of variance. This analysis of variance is presented in Table 12.

The Pa·DI interaction, the linear effect of Pop, and the quadratic effect of pH were the first, second, and third most significant factors, respectively. The linear effects of pH and N were each highly significant. The linear effect of DI was significant at 0.10 probability level and Ps and DI were each highly significant quadratic effects. The quadratic effects of N and Pop, and Ka and Ks, were significant at 0.05 and 0.20 probability levels, respectively. The interactions N·Pop and N·DI were each highly significant and the Ks·Ka interaction was significant. This equation:

$$\hat{Y} = 360.136 - 98.739pH - 1.086Ps + 0.102Ks + 0.002N - 0.202Pa + 0.693Ka + 2.675Pop - 1.731DI + 8.535pH^2 + 0.001Ps^2 - 0.00009Ks^2 - 0.0003N^2 + 0.001Pa^2 - 0.001Ka^2 - 0.019Pop^2 + 0.012DI^2 - 0.003N \cdot Pop + 0.0001N \cdot Pa - 0.0002Ks \cdot Ka - 0.003N \cdot Ps - 0.035pH \cdot Pa + 0.193pH \cdot Ps + 0.006N \cdot DI + 0.006Pa \cdot DI - 0.007Ka \cdot DI - 0.002Ps \cdot Pa \quad (2a)$$

has a R^2 of 0.602.

The variables were deleted which were not significant at a probability level equal to or less than 0.20. This process was repeated until at least one effect of each of the remaining variables in the analysis was significant at the specified probability level. At this point the analysis of variance

Table 12.--Analysis of variance of corn yield on "highest" expected potential soils of Tennessee (equation 2a).

Source of variation	Degrees of freedom		F
Total (N = 221)			
Mean	1		
Regression	26		
Linear		8	
N		1	6.84**
Pa		1	0.23
Ka		1	0.58
Ps		1	0.75
Ks		1	0.86
pH		1	8.10**
Pop		1	24.91**
DI		1	2.82+
Quadratic		8	
N^2		1	6.41*
Pa^2		1	1.40
Ka^2		1	2.42++
Ps^2		1	10.23**
Ks^2		1	1.85++
pH^2		1	21.62**
Pop^2		1	4.45*
DI^2		1	7.41**
Interaction		10	
N·Pop		1	13.47**
N·Pa		1	1.12
N·Ps		1	1.20
Pa·Ps		1	0.52
Ka·Ks		1	5.17*
pH·Pa		1	1.43
pH·Ps		1	0.45
N·DI		1	7.97**
Pa·DI		1	79.59**
Ka·DI		1	1.15
Residual	194		

contained eight linear variables and the quadratic effect for each variable, plus four linear x linear interactions. The analysis of variance showing source of variation, degrees of freedom, and F ratios is presented in Table 13. The Pa·DI interaction, the linear effect of Pop, and the quadratic effect of pH were the first, second, and third most significant factors, respectively, in explaining yield variation. The pH and N were each highly significant linear effects. The linear effects of Ps and DI were each significant at 0.10 level of probability. The quadratic effect of DI was highly significant. The N and Pop quadratic effects were each significant. The quadratic effects of Ka and Ks were significant at 0.10 and 0.20 levels of probability, respectively. The N·Pop and N·DI interactions were each highly significant and Ks·Ka interaction was significant. This "effective" prediction equation:

$$\hat{Y} = 438.153 - 119.069pH - 0.280Ps + 0.092Ks + 0.016N - 0.109Pa + 0.291Ka + 2.251Pop - 1.744DI + 10.030pH^2 + 0.001Ps^2 - 0.00007Ks^2 - 0.0004N^2 + 0.0006Pa^2 - 0.0008Ka^2 - 0.018Pop^2 + 0.012DI^2 + 0.0001N·Pop + 0.005N·DI - 0.00009Pa·DI - 0.0002Ks·Ka \quad \text{(2b)}$$

has a R^2 of 0.579.

Predicted corn yields as a function of applied P and drought index were obtained from the specific equation:

$$\hat{Y} = 117.465 + 0.460Pa - 1.657DI - 0.0021Pa^2 + 0.013DI^2 + 0.0062Pa·DI \quad \text{(2c)}$$

Table 13.--Analysis of variance of corn yield on "highest" expected potential soils of Tennessee (equation 2b).

Source of variation	Degrees of freedom		F
Total (N = 221)			
Mean	1		
Regression	20		
Linear		8	
N		1	6.84**
Pa		1	0.19
Ka		1	0.56
Ps		1	3.31+
Ks		1	1.11
pH		1	8.10**
Pop		1	24.91**
DI		1	2.82+
Quadratic		8	
N^2		1	6.41*
Pa^2		1	1.36
Ka^2		1	3.77+
Ps^2		1	0.58
Ks^2		1	1.92++
pH^2		1	21.62**
Pop^2		1	4.45*
DI^2		1	7.41**
Interaction		4	
N·Pop		1	13.47**
Ka·Ks		1	5.17*
N·DI		1	7.97**
Pa·DI		1	79.59**
Residual	200		

which has a R^2 of 0.379. These yields are presented in Table 14. Figure 8 is the production surface illustrating these predicted yields. Within the range of the data studied, the predicted yields decreased at all rates of applied P with increasing DI values and the predicted yields increased at all DI values with increasing rates of P applied. The relationship between corn yields and applied P at all DI levels was almost linear and positive. Therefore, it seems that a high rate of applied P may modify the effect of drought on corn yields. This may be due to differences in the availability of different nutrients and efficiency of water utilization by plants under conditions of varying moisture stresses and applied P.

The highest predicted yield (113.94 bu./A) was obtained with 25 pounds of applied P and a DI level of 10; whereas, the lowest predicted yield (64.84 bu./A) was obtained with no applied P and a DI level of 60.

Table 15 shows the predicted yields as a function of applied N and plant population obtained from the specific equation:

$$\hat{Y} = 40.481 + 0.239N + 4.589Pop - 0.0003N^2 - 0.031Pop^2 - 0.0047N \cdot Pop \quad \text{----------(2d)}$$

which has a R^2 of 0.447. A production surface illustrating these predicted yields is presented in Figure 9. The highest predicted yield (144.94 bu./A) was obtained with 150 pounds of applied N at a 24,000 population; and the lowest yield (58.34 bu./A) was obtained with no applied N at a 4,000 population. The

Table 14.--Predicted corn yields as a function of drought index and applied P (equation 2c).

Drought index	Pa (Lbs./A)						Ave.
	0	5	10	15	20	25	
10	102.19	104.74	107.19	109.54	111.79	113.94	108.23
20	89.52	92.37	95.12	97.77	100.32	102.77	96.31
30	79.45	82.60	85.65	88.60	91.45	94.20	86.99
40	71.98	75.43	78.78	82.03	85.18	88.23	80.27
50	67.11	70.86	74.51	78.06	81.51	84.86	76.15
60	64.84	68.89	72.84	76.69	80.44	84.09	74.63
Ave.	79.18	82.48	85.68	88.78	91.78	94.68	87.09

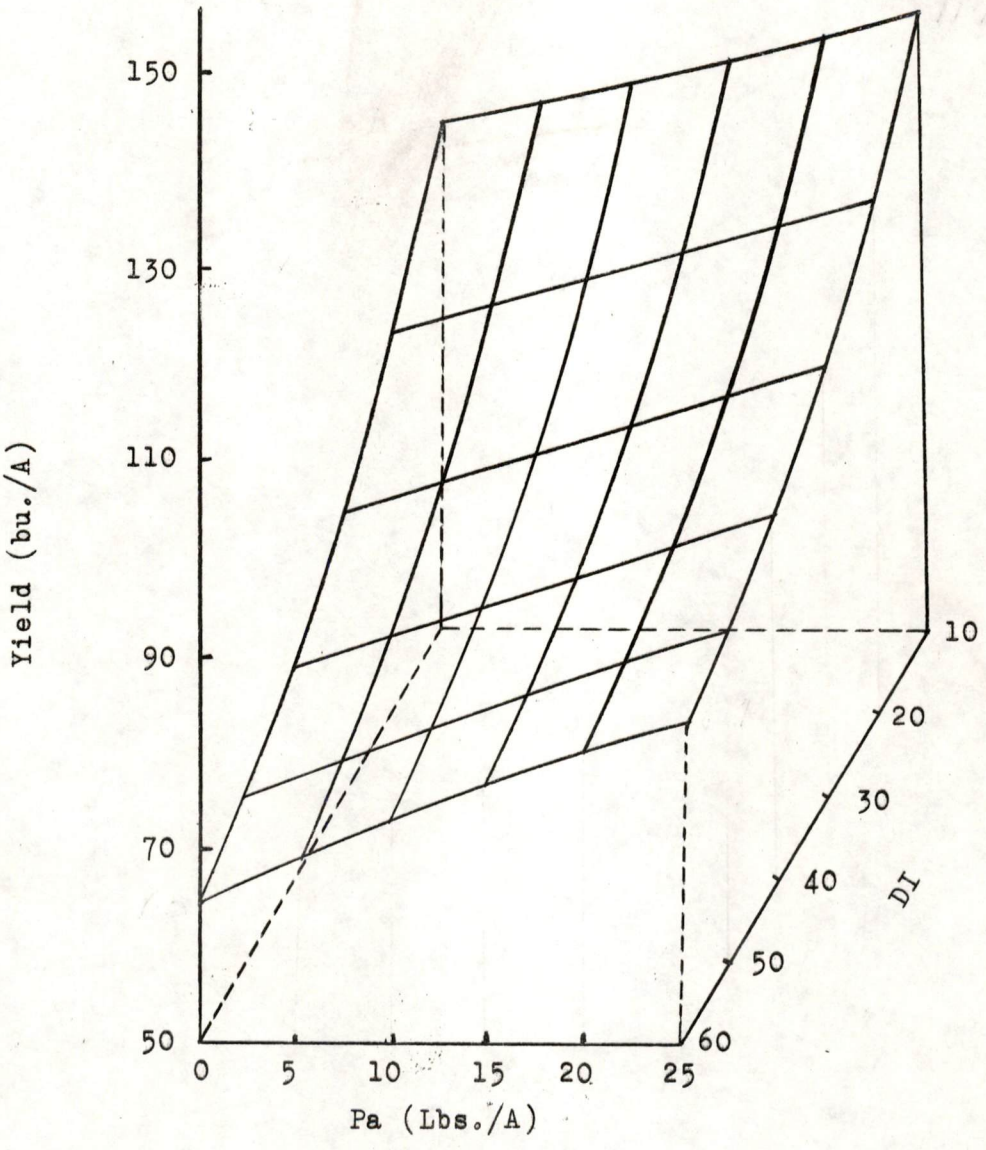


Figure 8.--Predicted corn production surface as a function of drought index and applied P on Tennessee soils with "highest" potential (equation 2c).

Table 15.--Predicted corn yields as a function of applied N and plant population (equation 2d).

Population (M Plants/A)	N (Lbs./A) 0	30	60	90	120	150	Ave.
4	58.34	64.67	70.47	75.72	80.44	84.62	72.38
8	75.20	80.98	86.21	90.90	95.05	98.66	87.83
12	91.08	96.29	100.96	105.08	108.67	111.72	102.30
16	105.96	110.61	114.71	118.28	121.30	123.78	115.77
20	119.86	123.94	127.48	130.48	132.94	134.86	128.26
24	132.76	136.27	139.25	141.68	143.58	144.94	139.75
Ave.	97.20	102.13	106.51	110.36	113.66	116.43	107.71

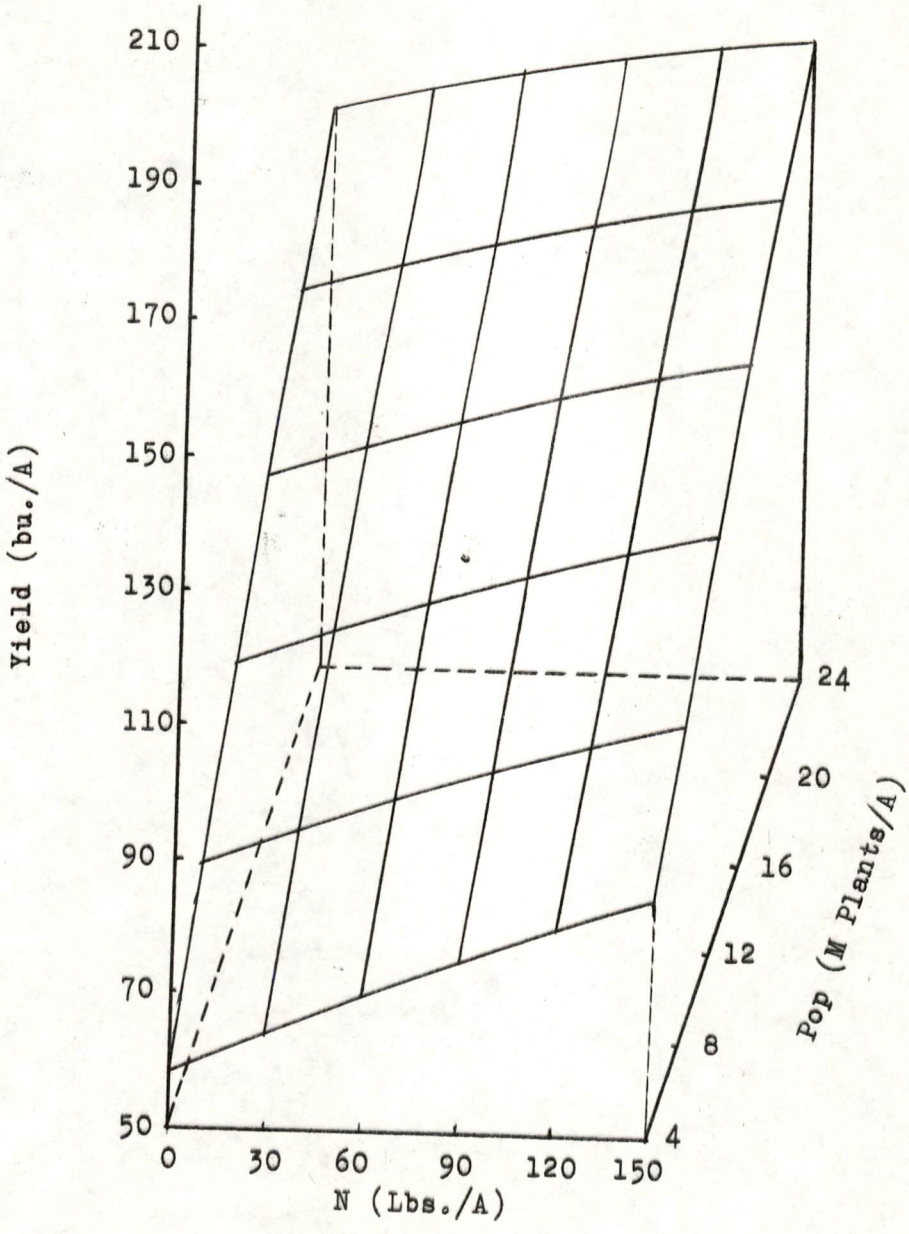


Figure 9.--Predicted corn production surface as a function of applied N and plant population on Tennessee soils with "highest" potential (equation 2d).

predicted yields across all rates of applied N increased with increasing populations; and similarly, the predicted yields across all levels of population increased with increasing rates of applied N. The increase in yield at all rates of applied N with increasing populations was greater than the increase in yield at all population levels with increasing rates of applied N. An increase in yield of 1.11 bu./A was obtained with 150 pounds of applied N and a 12,000 population upon a yield obtained with 30 pounds of applied N and a 16,000 population. Therefore, it will not be economically profitable to apply 120 pounds of extra N at 12,000 population to get this increase in yield. This indication may be of significance in selecting the proper plant population and N level to obtain economically profitable corn yields.

All Observations on Soil Group 2

One hundred and twenty-seven yield observations were collected on soils with a "high" expected potantial for producing corn. The same 26 terms, used in the analysis of variance presented in Table 12, were used in this analysis of variance. This analysis of variance showing source of variation, degrees of freedom, and F ratios is presented in Table 16. The interaction Pa·DI, the quadratic effect of Pop, and the linear effect of DI were the first, second, and third most significant factors, respectively. The linear effect of Pop was highly significant. The linear effects of Ka and Ks and the quadratic

Table 16.--Analysis of variance of corn yield on "high" expected potential soils of Tennessee (equation 3a).

Source of variation	Degrees of freedom		F
Total (N = 127)			
Mean	1		
Regression	25		
Linear		7	
N		1	0.37
Pa		-	0.00
Ka		1	1.71++
Ps		1	0.43
Ks		1	1.67++
pH		1	0.02
Pop		1	13.21**
DI		1	13.29**
Quadratic		8	
N^2		1	0.15
Pa^2		1	0.81
Ka^2		1	2.22++
Ps^2		1	1.73++
Ks^2		1	0.06
pH^2		1	1.33
Pop^2		1	25.44**
DI^2		1	0.06
Interaction		10	
N·Pop		1	1.56
N·Pa		1	0.98
N·Ps		1	0.57
Pa·Ps		1	0.25
Ka·Ks		1	0.48
pH·Pa		1	0.89
pH·Ps		1	0.93
N·DI		1	0.93
Pa·DI		1	50.00**
Ka·DI		1	0.69
Residual	101		

effects of Ka and Ps were each significant at the 0.20 level of probability.

It should be noted that Pa did not enter the analysis of variance. The reason it did not is due to a provision in the computer program whereby a minimum F value can be set, below which variables will not be entered. The minimum F value was set at 1×10^{-5} on the assumption that all the variables would have F values higher than this. Apparently, the one term which was not entered had F value lower than this minimum. This equation:

$$\hat{Y} = -21.708 + 13.756pH + 1.602Ps - 0.019Ks + 0.216N - 1.127Ka + 14.195Pop - 0.698DI - 2.239pH^2 - 0.048Ps^2 + 0.00006Ks^2 - 0.003N^2 - 0.001Pa^2 + 0.0002Ka^2 - 0.384Pop^2 + 0.002DI^2 - 0.012N \cdot Pop + 0.0002N \cdot Pa - 0.005N \cdot Ps + 0.239pH \cdot Pa + 0.198pH \cdot Ps + 0.001N \cdot DI - 0.015Pa \cdot DI + 0.017Ka \cdot DI - 0.0004Ks \cdot Ka - 0.006Ps \cdot Pa \quad \text{----------(3a)}$$

has a R^2 of 0.588.

The analysis of variance presented in Table 17 was developed using the same procedure as was used in developing the analysis of variance presented in Tables 4 and 13. Table 17 shows that the Pa·DI interaction, the quadratic effect of Pop, and the linear effect of DI were the first, second, and third most significant factors, respectively. The linear effect of Pop was highly significant and the linear effect of Ka was significant at a probability level of 0.10. The quadratic

Table 17.--Analysis of variance of corn yield on "high" expected potential soils of Tennessee (equation 3b).

Source of variation	Degrees of freedom		F
Total (N = 127)			
Mean	1		
Regression	11		
Linear		5	
Pa		1	0.27
Ka		1	2.80+
Ps		1	0.65
Pop		1	13.21**
DI		1	13.29**
Quadratic		5	
Pa^2		1	0.50
Ka^2		1	2.22++
Ps^2		1	1.70++
Pop^2		1	25.44**
DI^2		1	0.43
Interaction		1	
Pa·DI		1	50.00**
Residual	115		

effect of Ka and Ps were each significant at a probability level of 0.20. This "effective" prediction equation:

$$\hat{Y} = 4.933 + 1.857Ps + 0.647Pa - 0.431Ka + 13.163Pop - 0.748DI - 0.002Pa^2 + 0.003DI^2 - 0.393Pop^2 - 0.042Ps^2 + 0.002Ka^2 - 0.0008Pa \cdot DI \quad (3b)$$

has a R^2 of 0.551.

Predicted corn yields as a function of drought index and applied P were obtained from the specific equation:

$$\hat{Y} = 128.729 - 0.379Pa - 1.96DI - 0.0018Pa^2 + 0.00003DI^2 + 0.025Pa \cdot DI \quad (3c)$$

which has a R^2 of 0.392. These yields are presented in Table 18. The production surface illustrating these yields are presented in Figure 10. The predicted yields at all rates of applied P decreased with increasing drought index values; and the predicted yields at all drought index values increased, except at a drought index value of 15, with increasing rates of applied P. Apparently, there was no effect of increasing rates of applied P at a drought index value of 15 (lower moisture stress), but under higher moisture stresses, there was an almost positive linear relationship between applied P and predicted corn yields. Therefore, it appears that the effect of drought on corn yields may be modified with increasing rates of applied P. This may be due to differences in the availability of different nutrients and efficiency of water utilization by plants under conditions of varying moisture stresses and applied P.

Table 18.--Predicted corn yields as a function of drought index and applied P (equation 3c).

Drought index	Pa (Lbs./A)						
	0	5	10	15	20	25	Ave.
15	110.79	110.73	110.57	110.33	109.99	109.57	110.33
30	92.87	94.68	96.40	98.03	99.57	101.02	97.10
45	74.96	78.65	82.24	85.75	89.16	92.49	83.88
60	57.07	62.63	68.10	73.48	78.77	83.97	70.67
75	39.19	46.63	53.97	61.23	68.39	75.47	57.48
90	21.33	30.64	39.86	48.99	58.03	66.98	44.30
Ave.	66.04	70.66	75.19	79.63	83.99	88.25	77.29

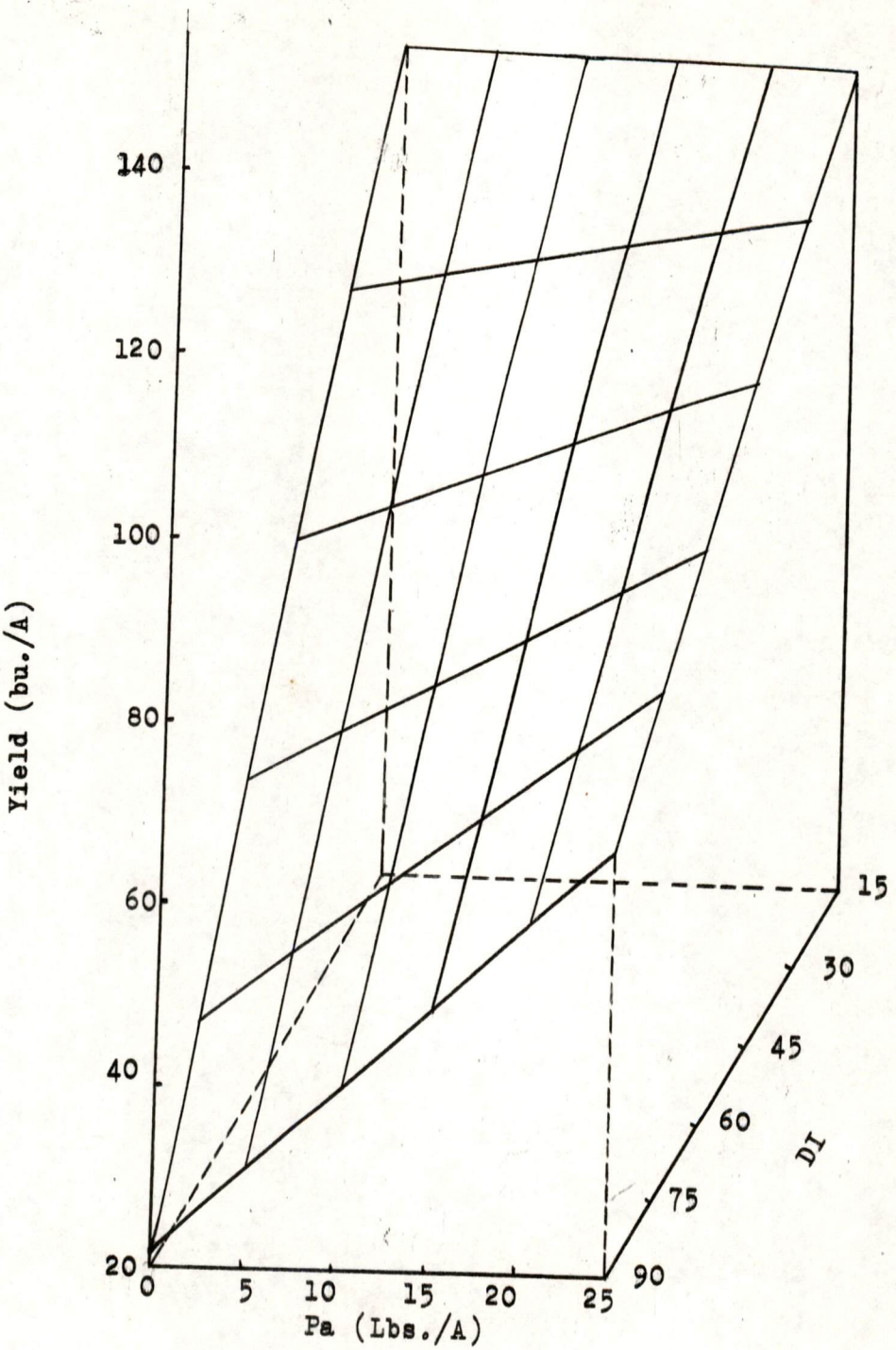


Figure 10.--Predicted corn production surface as a function of drought index and applied P on Tennessee soils with "high" potential (equation 3c).

The highest predicted yield (110.79 bu./A) was obtained with no applied P and a DI level of 15; whereas, the lowest yield (21.33 bu./A) was obtained with no applied P and a DI level of 90.

All Observations on Soil Group 3

One hundred and fifty-two observations were collected on soils with a "medium" expected potential for producing corn. The same 26 terms were used in this analysis of variance which were used in the analysis of variance presented in Table 12. This analysis of variance is presented in Table 19. The interaction pH·Pa, the quadratic effect of Pa, and the linear effect of Pop were the first, second, and third most significant factors, respectively. The linear effect of pH was highly significant and the linear effects of Ps and Pa were each significant at the 0.05 and 0.20 levels of probability, respectively. The quadratic effects of DI and Pop were each highly significant. The Ka and pH quadratic effects were each significant and Ks quadratic effect was significant at 0.20 probability level. The interactions Ks·Ka, N·Pop, and N·Ps were significant at 0.05, 0.10, and 0.20 levels of probability, respectively. This equation:

$$\hat{Y} = -315.324 + 114.793pH - 2.456Ps + 0.112Ks + 0.011N - 1.041Pa - 0.165Ka + 9.005Pop + 0.367DI - 10.362pH^2 + 0.013Ps^2 - 0.0001Ks^2 - 0.002N^2 + 0.003Pa^2 + 0.002Ka^2 - 0.241Pop^2$$

Table 19.--Analysis of variance of corn yield on "medium" expected potential soils of Tennessee (equation 4a).

Source of variation	Degrees of freedom		F
Total (N = 152)			
Mean	1		
Regression	26		
Linear		8	
N		1	0.009
Pa		1	2.04++
Ka		1	0.27
Ps		1	4.02*
Ks		1	1.44
pH		1	8.49**
Pop		1	26.40**
DI		1	0.36
Quadratic		8	
N^2		1	0.11
Pa^2		1	32.32**
Ka^2		1	5.38*
Ps^2		1	0.57
Ks^2		1	2.28++
pH^2		1	4.42*
Pop^2		1	23.81**
DI^2		1	26.31**
Interaction		10	
N·Pop		1	3.50+
N·Pa		1	0.42
N·Ps		1	1.68++
Pa·Ps		1	0.35
Ka·Ks		1	6.30*
pH·Pa		1	175.24**
pH·Ps		1	0.55
N·DI		1	0.83
Pa·DI		1	0.29
Ka·DI		1	0.03
Residual	125		

$- 0.009DI^2 - 0.003N \cdot Pop + 0.005N \cdot Ps + 0.0003N \cdot Pa + 0.287pH \cdot Pa$

$+ 0.229pH \cdot Ps - 0.0009N \cdot DI + 0.003Ka \cdot DI - 0.003Pa \cdot DI$

$- 0.0008Ks \cdot Ka - 0.004Ps \cdot Pa$ ----------(4a)

has a R^2 of 0.827.

The analysis of variance presented in Table 20 was developed by the same procedure as was used in developing the analysis of variance presented in Table 13. Table 20 shows that the pH·Pa interaction, the quadratic effect of applied P, and the linear effect of Pop were the first, second, and third most significant factors, respectively. The quadratic effects of DI and Pop, and the linear effect of pH were highly significant factors affecting corn yields. The Ks·Ka interaction, the quadratic effects of Ka and pH, and the linear effect of Ps were significant factors in accounting for variation in corn yields. The interaction N·Pop was significant at 0.10 level of probability. The N·Ps interaction, the quadratic effect of Ks, and the linear effect of Pa were each significant at 0.20 probability level. This "effective" prediction equation:

$\hat{Y} = -339.288 + 119.862pH - 0.953Ps + 0.131Ks - 0.039N - 1.059Pa$

$+ 0.006Ka + 9.301Pop + 0.207DI - 10.484pH^2 + 0.002Ps^2$

$- 0.0002Ks^2 + 0.000003N^2 - 0.002Pa^2 + 0.002Ka^2 - 0.246Pop^2$

$- 0.008DI^2 - 0.003N \cdot Pop - 0.0009Ks \cdot Ka + 0.005N \cdot Ps$

$+ 0.251pH \cdot Pa$ ----------(4b)

has a R^2 of 0.823.

Predicted corn yields as a function of applied P and pH were obtained from the specific equations:

Table 20.--Analysis of variance of corn yield on "medium" expected potential soils of Tennessee (equation 4b).

Source of variation	Degrees of freedom		F
Total (N = 152)			
Mean	1		
Regression	20		
Linear		8	
N		1	0.44
Pa		1	2.04++
Ka		1	0.002
Ps		1	4.02*
Ks		1	1.44
pH		1	8.49**
Pop		1	26.40**
DI		1	0.43
Quadratic		8	
N^2		1	0.0002
Pa^2		1	32.32**
Ka^2		1	5.38*
Ps^2		1	0.02
Ks^2		1	2.28++
pH^2		1	4.42*
Pop^2		1	23.81**
DI^2		1	26.33**
Interaction		4	
N·Pop		1	3.50+
N·Ps		1	1.68++
Ka·Ks		1	6.30*
pH·Pa		1	175.24**
Residual	131		

$\hat{Y} = -323.946 + 126.71pH - 0.884Pa - 10.59pH^2 - 0.0037Pa^2$

$+ 0.318pH \cdot Pa$ ----------(4c)

which has a R^2 of 0.637. These yields are presented in Table 21. A production surface illustrating the effect of these variables on corn yields is shown in Figure 11. The predicted yields at all rates of applied P increased with an increasing pH up to a pH of 6.0 and the predicted yields at all pH levels increased with increasing rates of applied P. Beyond a pH of 6.0 the predicted yields decreased at all rates of applied P except at the 20 and 25 pound levels of applied P. At the 20 and 25 pound rates of applied P yields increased when the pH increased from 6.0 to 6.5, but the extent of increase in yield was negligible. Beyond pH 6.5 yields decreased at the 20 and 25 pound rates of applied P. This may be due to the influence of different pH levels on the availability of different nutrients to plants, and it appears that a pH 6.0 to 6.5 with high rates of applied P may be favorable for obtaining maximum corn yields.

All Observations on Soil Group 4

Fourty-four observations were collected on soils with a "low" expected potential for producing corn. The analysis of variance presented in Table 22 had the same 26 terms which were in the analysis of variance shown in Table 12. Table 22 shows that the linear effect of Pop and the quadratic effect of DI were each significant at the 0.05 level of probability. The

Table 21.--Predicted corn yields as a function of applied P and pH (equation 4c).

Pa (Lbs./A)	pH 5.0	5.5	6.0	6.5	7.0	Ave.
0	44.85	52.61	55.07	52.24	44.11	49.78
5	48.29	56.84	60.10	58.06	50.73	54.81
10	51.54	60.89	64.94	63.70	57.16	59.64
15	54.61	64.75	69.60	69.10	63.41	64.29
20	57.49	68.43	74.07	74.42	69.47	68.77
25	60.19	71.92	78.36	79.50	75.35	73.06
Ave.	52.83	62.57	67.02	66.18	60.04	61.72

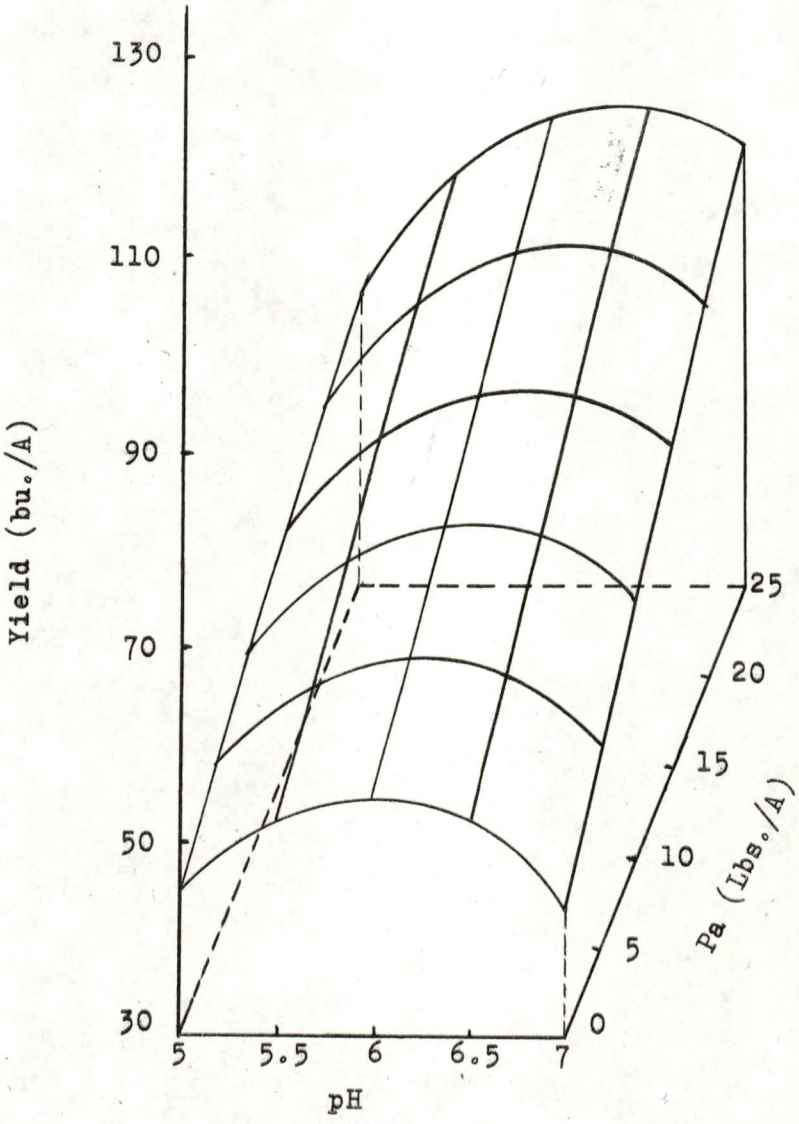


Figure 11.--Predicted corn production surface as a function of applied P and pH on Tennessee soils with "medium" potential (euqation 4c).

Table 22.--Analysis of variance of corn yield on "low" expected potential soils of Tennessee (equation 5a).

Source of variance	Degrees of freedom		F
Total (N = 44)			
Mean	1		
Regression	26		
Linear		8	
N		1	1.89++
Pa		1	0.16
Ka		1	0.17
Ps		1	4.34+
Ks		1	1.86++
pH		1	3.22+
Pop		1	6.53*
DI		1	0.59
Quadratic		8	
N^2		1	1.71++
Pa^2		1	1.13
Ka^2		1	1.02
Ps^2		1	1.69
Ks^2		1	2.46++
pH^2		1	1.36
Pop^2		1	0.04
DI^2		1	4.23*
Interaction		10	
N·Pop		1	0.64
N·Pa		1	1.34
N·Ps		1	0.70
Pa·Ps		1	3.10+
Ka·Ks		1	0.67
pH·Pa		1	0.58
pH·Ps		1	2.59++
N·DI		1	2.31++
Pa·DI		1	0.21
Ka·DI		1	0.51
Residual	17		

linear effects of pH and Ps were each significant at 0.10 probability level. The linear and the quadratic effects of Ks and N were each significant at 0.20 probability level. The interaction Ps·Pa was significant at 0.10 probability level and the interactions pH·Ps and N·DI were each significant at the 0.20 level of probability. This equation:

$$\hat{Y} = -866.258 + 378.214pH - 12.122Ps - 0.289Ks + 0.983N - 7.335Pa + 0.968Ka + 12.698Pop - 1.496DI - 39.743pH^2 - 0.018Ps^2 + 0.0003Ks^2 - 0.0008N^2 - 0.016Pa^2 - 0.011Ka^2 - 0.239Pop^2 - 0.007DI^2 - 0.091N \cdot Pop + 0.014N \cdot Pa - 0.022N \cdot Ps + 1.286pH \cdot Pa + 2.565pH \cdot Ps - 0.035N \cdot DI + 0.029Pa \cdot DI + 0.032Ka \cdot DI + 0.004Ks \cdot Ka - 0.032Ps \cdot Pa \quad \text{----------(5a)}$$

has a R^2 of 0.764.

The analysis of variance presented in Table 23 was developed by the same procedure as was used in developing the analysis of variance shown in Table 13.

Table 23 shows that none of the factors were highly significant. There was a significant linear effect for Pop and a significant quadratic effect for DI. The linear effect of Ks and the quadratic effects of N, Ks and pH were each significant at 0.20 probability level.

The linear effect of Pop was the first significant factor entering the analysis and it explained 13.5 percent of the total yield variation. The second significant factor entering the analysis was the quadratic effect of DI. The "effective"

Table 23.--Analysis of variance of corn yield on "low" expected potential soils of Tennessee (equation 5b).

Source of variation	Degrees of freedom		F
Total (N = 44)			
Mean	1		
Regression	10		
Linear		5	
N		1	0.55
Ks		1	1.86++
pH		1	0.26
Pop		1	6.53*
DI		1	0.41
Quadratic		5	
N^2		1	1.71++
Ks^2		1	2.46++
pH^2		1	1.98++
Pop^2		1	0.22
DI^2		1	4.23*
Residual	33		

prediction equation contained no significant interaction term. This "effective" prediction equation:

$$\hat{Y} = -477.476 + 158.906pH + 13.844Pop + 0.03Ks + 0.243N + 0.448DI - 0.536Pop^2 - 13.106pH^2 - 0.0009N^2 - 0.0002Ks^2 - 0.012DI^2 \quad (5b)$$

has a R^2 of 0.403.

Table 24 shows the predicted yields as a function of drought index and plant population obtained from the equation:

$$\hat{Y} = -38.515 + 26.134Pop - 0.368DI - 1.384Pop^2 - 0.011DI^2 + 0.071Pop \cdot DI \quad (5c)$$

which has a R^2 of 0.251. The production surface showing the effects of DI and Pop on yields is illustrated in Figure 12. Within the range of the data studied, the predicted yields increased at all values of drought index up to a population of 10,000 plants per acre after which they decreased. The predicted yields were almost constant at populations of 6, 7, and 8 thousand plants per acre when the DI values increased from -3 to 15. Beyond a population of 8,000 plants per acre the predicted yields increased when the DI value increased from -3 to 15. This may be due to other factors affecting corn yields but are not accounted for in the specific equation, 5c. The predicted yields decreased at all plant population levels with increasing DI values beyond 15.

The highest predicted yield (87.08 bu./A) was obtained with a population of 10,000 plants per acre and a drought index level of 15; whereas, the lowest predicted yield (43.87 bu./A)

Table 24.--Predicted corn yields as a function of drought index and plant population (equation 5c).

Drought index	Population (M Plants/A)						
	6	7	8	9	10	11	Ave.
-3	68.19	76.12	81.28	83.68	83.30	80.16	78.79
5	68.48	76.98	82.71	85.67	85.86	83.29	80.49
15	66.86	76.07	82.51	86.18	87.08	85.22	80.98
25	63.04	72.96	80.11	84.49	86.10	84.95	78.60
35	57.02	67.65	75.51	80.60	82.92	82.48	74.36
50	43.87	55.56	64.48	70.64	74.03	74.65	63.87
Ave.	61.24	70.89	77.76	81.87	83.21	81.79	76.18

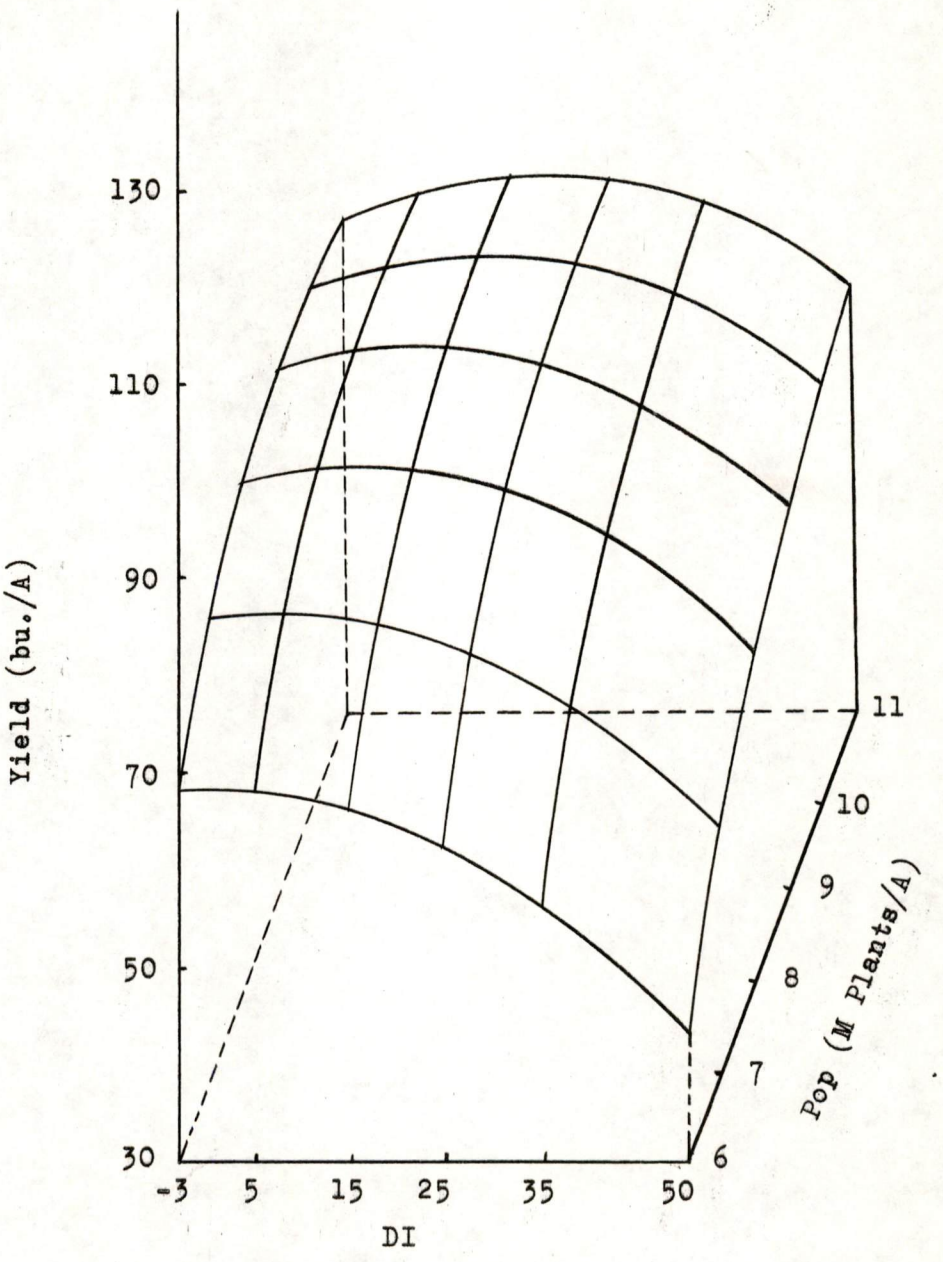


Figure 12.--Predicted corn production surface as a function of drought index and plant population on Tennessee soils with "low" potential (equation 5c).

was obtained with a population of 6,000 plants per acre at a drought index level of 50. The difference in yields of drought index values -3 and 50 decreased with increasing plant population, and the difference in yields of plant populations 6 and 11 thousands increased with increasing drought index. Thus, it seems probable with increasing moisture stress that a higher plant population will not decrease yields more than a lower plant population.

An Evaluation of General and "Effective" Equations as a Predictor of Corn Yields on Tennessee Soils

A comparative study of R^2 values of general and "effective" prediction equations presented in Table 25 revealed that the variables not significant at the probability level equal to or less than 0.20 were not limiting in corn production on Tennessee soils in general and on highest, high, and medium potential soils of Tennessee in particular; but on low potential soils of Tennessee they (deleted variables) accounted for considerable amount of variation in corn yields. In other words, it may be stated that it would not make much difference in using the general or "effective" equation for predicting corn yields on 1, 2, and 3 soil groups but on soil group 4, the general equation would be a better predictor of corn yields than the "effective" equation.

Table 25.--R^2 values of general and "effective" prediction equations.

Sets of observations	General equation	"Effective" equation
All observations combined	0.564	0.531
All observations on soil group 1	0.602	0.579
All observations on soil group 2	0.558	0.551
All observations on soil group 3	0.827	0.823
All observations on soil group 4	0.764	0.403

A Comparative Study of the Analyses of Variance For the "Effective" Prediction Equations (2b, 3b, 4b, and 5b)

The linear effect of Pop was highly significant on highest, high, and medium potential soils, and it was significant on the low potential soils. The quadratic effect of Pop was highly significant on high and medium potential soils, and it was significant on highest potential soils. The linear effect of DI was highly significant on high potential soils, and the quadratic effect of DI was highly significant on highest and medium potential soils, and it was significant on low potential soils. The linear and quadratic effects of pH were highly significant and significant, respectively, on highest and medium potential soils. The linear and quadratic effects of N were highly significant and significant, respectively, on highest potential soils. The quadratic effects of Pa and Ka, and the interaction Ka·Ks were each significant on medium potential soils. The interaction Ka·Ks was also significant on highest potential soils. The interactions N·DI and N·Pop were highly significant on highest potential soils. The interaction Pa·DI was highly significant on highest and high potential soils. The interaction pH·Pa was highly significant on medium potential soils.

The above comparative study also revealed that plant population had the most significant effect on corn yields on each of four soil groups.

CHAPTER V

SUMMARY AND CONCLUSIONS

Five hundred and forty-four corn yield observations which were available from 1950 through 1961 were collected from several sources. Each yield observation was accompanied with information on soil test values (pH, K and P), applied N, P_2O_5, and K_2O in pounds per acre, plant population in thousands of plants per acre, planting date, year and location (county). Most of the yield observations were from the year 1956 through 1961. The daily rainfall record for the months of April through September was obtained for each year at each location.

The data collected were used to: (1) interpret rainfall and soil moisture information in terms of drought as one production factor; (2) develop methodology to fit appropriate drought values along with varying levels of selected management factors in quadratic prediction equations; (3) develop a mathematical relationship, in terms of a quadratic function, between observed yields and varying levels of selected production factors; (4) develop "effective" prediction equations for predicting corn yields; (5) to make an agronomic interpretation of the findings of this study.

The soils were classified into four categories as "highest", "high", "medium", and "low" based on estimates of expected potential for producing corn.

Multiple regression techniques employing a quadratic model were used to analyze the data. Four general regression equations, one corresponding to the drought index level of each moisture base (1 inch through 4 inch) were computed in each set of observations with several production factors expressed as independent variables. The highest R^2 value was used to select one general regression equation in each set of observations. Five general regression equations were selected based on five sets of observations. These five sets of observations were: (1) all of the 544 observations; (2) all of the 221 observations on group 1; (3) all of the 127 observations on group 2; (4) all of the 152 observations on group 3; and (5) all of the 44 observations on group 4. An "effective" prediction equation in which at least one effect of each variable was significant at a probability level equal to or less than 0.20 was developed for each of the five sets of observations. "Specific" prediction equations were developed for the most significant variables in analysis of variance for "effective" prediction equations.

In the first set of observations, the "effective" prediction equation had a R^2 of 0.531. The positive linear effects of Ks, N, Pop, and Pa, and the positive interaction Pa·DI were each highly significant. The negative linear effects of Pop and Ka, and the negative interactions N·Pop, pH·Pa, and Ks·Ka were each highly significant. In the second set of

observations, the "effective" prediction equation had a R^2 of 0.579. The highly significant positive interactions were N•Pop and N•DI. The highly significant negative interaction was Pa•DI. In the third set of observations, the "effective" prediction euqation had a R^2 of 0.551. The highly significant negative interaction was Pa•DI. In the fourth set of observations, the "effective" prediction equation had a R^2 of 0.823. The highly significant positive interaction was pH•Pa. In the fifth set of observations, the "effective" prediction equation had a R^2 of 0.403. The positive linear effect of Pop and the negative quadratic effect of DI were each significant at 0.05 level of probability.

The different sets of observations generally yielded different equations and the variables used did not always have the same significance in all equations.

In general, the "specific" equations had very low R^2 values since each "specific" equation contained only two selected significant variables with a quadratic effect for each variable, plus their linear x linear interaction term. Therefore, on the basis of the trends in the results obtained, the following conclusions were drawn:

A. The effects of drought on corn yields may be modified with increasing rates of N, P, and K application.

B. A high rate of N application with a high level of plant population may be necessary to obtain a high corn yield.

C. A high level of soil K may mask the effect of high

rates of potash application on corn yields.

D. A pH between 6.0 to 7.0 with high rates of applied P seems to have beneficial effects on corn yields.

E. It seems probable with increasing moisture stress that a higher plant population will not decrease yields more than a lower plant population.

F. Among all the factors studied, plant population appeared as the most significant factor affecting corn yields on all soil groups.

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APPENDICES

APPENDIX A

AVAILABLE WATER HOLDING CAPACITY OF THE TOP THREE FEET OF SOILS IN TENNESSEE AS CALCULATED FROM UNPUBLISHED DATA OF LONGWELL, T.J.

Group 1

1	2	3	4	5
Soils	Profile depth	Texture	A.W.H.C. in inches/inch	A.W.H.C. of the top 3 ft. soils in inches
Staser	0" - 10"	sil or fsl	0.23 or 0.17	8.02 or 7.42
A_0, A_1	10" - 36"	loam or loam	0.22 or 0.22	
Emory	0" - 8"	sil	0.23	7.44
B_1, B_2	8" - 36"	sil	0.20	
Huntington	0" - 8"	sil or fsl	0.21 or 0.17	7.56 or 6.96
A_1, B_1, B_2	8" - 40"	sil or loam	0.21 or 0.20	
Congaree	0" - 12"	sil or fsl	0.19 or 0.17	7.32 or 7.08
A_1, B_1	12" - 42"	sil or loam	0.21 or 0.21	
Greendale	0" - 10"	sil	0.23	7.06
B_1	10" - 20"	sil	0.22	
	20" - 30"	sicl	0.17	
	30" - 48"+	sicl	0.16	
Sequatchie	0" - 7"	fsl or loam	0.17 or 0.19	7.06 or 7.09
A_1, A_2, B_1, B_2	7" - 25"	sil or sicl	0.21 or 0.21	
	25"+	sicl or cl	0.19 or 0.18	
Neubert	0" - 9"	fsl or loam	0.18 or 0.19	7.17 or 7.26
A_1	9" - 36"	loam or sil	0.21 or 0.21	

Group 2

1	2	3	4	5
Hermitage	0" - 10"	sil	0.17	5.98
B_1, B_2, C_1, C_2	10" - 16"	sicl	0.18	
	16" - 38"	sicl	0.16	
Etowah	0" - 8"	sil	0.19	5.88
B_1, B_2, C_2	8" - 24"	sicl	0.16	
	24"+	sicl	0.15	
Minvale	0" - 11"	sil	0.19	6.09
B_1, B_2, C_1, C_2	11" - 36"	sicl	0.16	
Alcoa	0" - 8"	loam	0.18	5.08
B_1	8" - 28"+	cl	0.13	
Hartsells	0" - 18"	loam	0.17	5.78
B_1, B_2, C_1, C_2	18" - 30"+	sicl	0.15	

Group 3

Dunmore	0" - 7"	sil	0.20	5.25
	7" - 10"	sicl	0.17	
B_2, C_2	10" - 26"	sic	0.14	
	26"+	c or sic	0.11	

APPENDIX A (continued)

1	2	3	4	5
Dewey	0" - 8"	sil	0.18	5.48
B_2, C_1, C_2	8" - 14"	sicl	0.16	
	14" - 30"+	sic	0.14	
Decatur	0" - 8"	sil	0.18	5.48
B_2, C_1, C_2	8" - 14"	sicl	0.16	
	14" - 42"	sic or c	0.14	
Cumberland	0" - 10"	sil	0.19	5.33
	10" - 15"	sicl	0.17	
B_2, C_2	15" - 24"	sic	0.14	
	24"+	c	0.12	
Waynesboro	0" - 11"	loam	0.18	5.33
	11" - 16"	cl	0.15	
B_2, C_2	16" - 38"	c	0.13	
Fullerton	0" - 9"	sil	0.17	
B_2	9" - 14"	sil	0.16	4.55
	14" - 20"	sicl	0.11	
	20" - 36"	sic or c	0.10	

Group 4

1	2	3	4	5
Fullerton	0" - 7"	sil	0.17	
C_1, C_2, D_1, D_3	7" - 14"	sicl	0.14	4.37
	14" - 30"+	sic or c	0.10	
Cumberland	0" - 8"	sil	0.15	
D_1	8" - 15"	sicl	0.13	4.30
	15" - 24"	sic	0.11	
	24"+	c	0.10	
Dunmore	0" - 8"	sicl	0.15	
D_2	8" - 24"	sic	0.12	4.44
	24"+	c	0.11	
Decatur	0" - 8"	sil	0.15	
D_2	8" - 14"	sicl	0.13	4.62
	14" - 39"	sic or c	0.12	

Abbreviations used:

fsl = fine sandy loam
sil = silty loam
sicl = silty clay loam
sic = silty clay
cl = clay loam
c = clay

APPENDIX B

GROUPING OF SIMILAR SOILS

GROUP 1

Staser A_0, A_1

Emory B_1, B_2

Huntington A_1, B_1, B_2

Congaree A_1, B_1

Greendale B_1

Sequatchie A_1, A_2, B_1, B_2

Neubert A_1

State

Ennis

GROUP 2

Etowah B_1, B_2, C_2

Hermitage B_1, B_2, C_1, C_2

Minvale B_1, B_2, C_1, C_2

Alcoa B_1

Hartsells B_1, B_2, C_1, C_2

GROUP 3

Dunmore B_2, C_2

Dewey B_2, C_1, C_2

Decatur B_2, C_1, C_2

Cumberland B_2, C_2

Waynesboro B_2, C_2

Fullerton B_2

Pembroke

GROUP 4

Fullerton C_1, C_2, D_1, D_3

Cumberland D_1

Dunmore D_2

Decatur D_2

APPENDIX C

AVERAGE DAILY EVAPOTRANSPIRATION RATES CALCULATED BY PENMAN EUQATION FOR SELECTED LOCATIONS APPLICABLE TO VARIOUS AREAS OF THE TENNESSEE VALLEY

Month	Knoxville Tennessee Inches	Nashville Tennessee Inches	Memphis Tennessee Inches
April	0.11	0.11	0.13
May	0.13	0.14	0.15
June	0.16	0.17	0.18
July	0.15	0.17	0.18
August	0.13	0.15	0.16
September	0.11	0.12	0.13
October	0.06	0.07	0.08

APPENDIX D

PENMAN EQUATION

$$E_T = \frac{\Delta H + 0.27Ea}{\Delta + 0.27}$$

Where ET = evapotranspiration in mm. per day.

Δ = incremental change in vapor pressure with absolute temperature at the surface as a function of air temperature.

H = net heat absorption at the surface in mm. of water.

Ea = a function of saturation deficit and wind velocity.

APPENDIX E

The procedure of drought day computation as stated in terms of an equation:

$$Ai = (Ai - 1) - Ei + Pi$$

Where Ai = amount of moisture held in the soil in inches on the day, i.

Ai-1 = amount of moisture in the soil in inches on the previous day (e.g. 0.32").

Ei = the loss of moisture in inches from the soil by evapotranspiration on the day, i (e.g. 0.11").

Pi = the amount of precipitation in inches that may occur on the day, i (e.g. 0.13").

Therefore, the amount of moisture (Ai) in the soil on day i is:

$$Ai = 0.32 - 0.11 + 0.13$$

$$= 0.34"$$

When the value of Ai is less than Ei then that day is termed as a drought day, and is represented by the symbol '0'.

APPENDIX F

A SAMPLE CALCULATION OF DROUGHT DAY INCIDENCE

Potential Daily Evapotranspiration = 0.11 inch

Date	Rainfall in inches	Moisture Base 1"	2"	3"	4"	6"
9	0.30	1.00	2.00	3.00	4.00	6.00
10	-	0.89	1.89	2.89	3.89	5.89
11	-	0.78	1.78	2.78	3.78	5.78
12	-	0.67	1.67	2.67	3.67	5.67
13	-	0.56	1.56	2.56	3.56	5.56
14	-	0.45	1.45	2.45	3.45	5.45
15	-	0.34	1.34	2.34	3.34	5.34
16	-	0.23	1.23	2.23	3.23	5.23
17	-	0.12	1.12	2.12	3.12	5.12
18	-	0.01	1.01	2.01	3.01	5.01
19	-	0	0.90	1.90	2.90	4.90
20	-	0	0.79	1.79	2.79	4.79
21	-	0	0.68	1.68	2.68	4.68
22	1.35	1.00	1.92	2.92	3.92	5.92
Total number of drought days		3	Nil	Nil	Nil	Nil

APPENDIX G

EQUATION USED FOR DROUGHT INDEX COMPUATION

$$\hat{Y} = 99.04 - 0.096A - 1.376B + 5.232C - 1.736D - 0.403C^2 - 0.146CB - 0.055CD + 0.042BD$$

$$\hat{Y} = 99.04 - (0.096A + 1.376B - 5.232C + 1.736D + 0.403C^2 + 0.146CB + 0.055CD - 0.042BD)$$

$$DI = 0.096A + 1.376B - 5.232C + 1.736D + 0.403C^2 + 0.146CB + 0.055CD - 0.042BD$$

Where DI = drought index

A = number of drought days occurring in the first 33 days during the growing season of corn

B = number of drought days in the next 32 days

C = number of drought days in the next 14 days (tasseling period)

D = number of drought days during 31 days after tasseling.