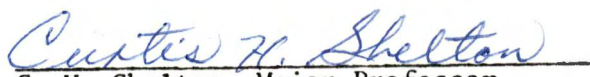
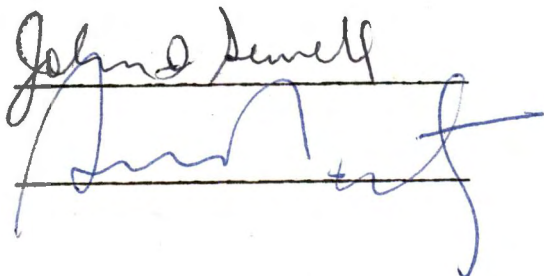


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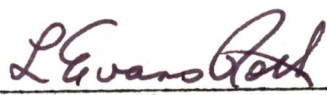
I am submitting herewith a thesis written by Naufal Al-Masri entitled "Efficient Water Management For Optimum Crop Production." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.


C. H. Shelton, Major Professor

We have read this thesis and
recommend its acceptance:



Accepted for the Council:


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Graduate Studies and Research

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EFFICIENT WATER MANAGEMENT FOR OPTIMUM CROP PRODUCTION

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Naufal Al-Masri

March 1977

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ABSTRACT

A field containing approximately 12 acres of corn and located on the University of Tennessee Holston farm was selected for this study. The objectives of this study were (1) to determine the effects of soil moisture variation due to topography and soil type, (2) to determine the effects of soil moisture variation on corn yield, and (3) to compare observed soil moisture deficiency occurrence with those predicted by using a soil-moisture balance procedure. Twenty-five soil moisture access tubes were installed throughout the field after April 30, 1976, on which date the corn was planted. Weekly moisture measurements were made during the corn-growing season. Corn yield (green matter basis) was determined on August 10, 1976.

Lindside silt loam had the highest average soil moisture during the growing season, followed by Altavista loam and Huntington silt loam, in that order. Corn yield was influenced little by soil moisture differences among soil types.

An analysis of variance was applied to the yield data for the three months of the growing season. This analysis indicated that the soil moisture level within different elevation ranges did not significantly relate to the corn yield.

Based on the results of this one-year study the following conclusions were reached:

1. The influences of soil type and elevation range on yield were not significant in this year of study probably because

precipitation level was 1.6 inches above normal during the growing season.

2. Corn yield increased as moisture content approached field capacity throughout the soil profile.
3. Soil moisture was greater in sites located on level ground where frequent ponding occurred.
4. The predicted and measured soil moisture were in close agreement except during the first month of the growing season.
5. Soil moisture deficiency occurred in the upper foot of the soil profile, while moisture excess occurred at depths of two and three feet.
6. The actual number of soil moisture deficit days was 42 in contrast to 20 predicted days of soil moisture deficiency.

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CHAPTER I

INTRODUCTION

The influence of water on the world food supply is extremely important. As population increases, resulting in a greater demand on the water resource, efficient water management in food and fiber production will become increasingly important. The agricultural industry, the greatest user of water, must improve the efficiency with which that water is used. Agricultural engineers have a responsibility to develop new practices that will permit the collection, and storage in the soil profile, a greater percentage of precipitation.

Proper water management implies water-use efficiency and water-application efficiency. Water-use efficiency is the ratio of the water beneficially used to the water delivered to the area, while water-application efficiency is the ratio of the water stored in the soil root zone to the water delivered to the area by an irrigation system. Improving the ability of soil to store moisture is of major concern for efficient water management. The soil water used by the plant is the quantity available between field capacity and wilting point. Field capacity closely corresponds to $1/3$ atmosphere tension, while the wilting point ranges between 7 and 32 atmosphere tension, with 15 atmospheres tension being a satisfactory average. When the soil reaches some predetermined moisture tension, the plant should be irrigated; for example, corn should be irrigated at four bars tension.

The moisture in the soil profile is affected by soil characteristics and by surface slope. For example coarse silt and fine sand are the soil fraction that have the highest available water holding capacity. The moisture content in the soils located at the base of slopes is generally greater than that at the surrounding soils on the slopes. Determination of the soil's ability to hold available moisture is of particular importance in planning for optimum production of agricultural crops.

Agricultural drought is a result of soil moisture deficiency in the root zone of the soil profile. One of the numerous purposes of irrigation, even in humid areas, is to overcome periods of drought so that crop yield and net profits may be increased. Conversely, excess soil moisture may cause reduction in crop yield. Variation in soil moisture content within a field causes problems in machinery use, crop germination, growth uniformity, and crop harvesting. Careful study of soil moisture deficits and excesses will help to better understand and apply efficient water management practices. The purpose of this study was to relate crop yield to variations in soil moisture under field conditions. Information thus obtained could be used to determine the need for such water management practices as irrigation and drainage.

The objectives of this study were (1) to determine the effects of soil moisture variation due to topography and soil type, (2) to determine the effects of soil moisture variation on corn yield, and (3) to compare observed soil moisture deficiency occurrence with those predicted by using a soil-moisture balance procedure.

CHAPTER II

LITERATURE REVIEW

I. Relation of Soil Moisture to Crop Yield

Understanding the general conditions that effect soil moisture is necessary for efficient water management for crop production. Crop yield is intimately related to soil moisture as well as to atmospheric conditions. Moisture excesses and deficits contribute to reduction in crop yields. Baier and Robertson (2) found that crop yields were more closely related to soil moisture than to atmospheric factors. They treated the soil profile as a sequence of zones, and correlated the soil moisture in each zone with crop yield for different stages of plant growth. Multiple correlation analysis indicated that soil moisture was the best estimator of crop yields, followed in order by minimum atmospheric temperature and maximum temperature. Seasonal rainfall was found to be unstable as a basis for yield estimation. Carreker et al. (5) proved that corn yields related directly to total and effective rainfall and inversely to number of drought days per year. Jensen and Sletten (11) reported that grain sorghum yields on Pullman clay loam were not materially affected by the levels of soil water if the available moisture in the 0-47 inch root zone was maintained above 30 percent. Musick and Sletten (18) found that grain sorghum yields were not reduced significantly until available soil water in the 0-47 inch depth zone was depleted below 2.0 inches during the boot stage to dough stage

of grain development. The 2.0 inches corresponded to 25 percent available in the Richfield soil and 30 percent in the Pullman soil used in the study. Yields of irrigated winter wheat as reported by Musick et al. (17) declined until soil water in the 0-47 inch depth zone was depleted to the wilting point, and approached the wilting point in the 71-inch profile during grain filling. Musick et al. (16) observed the depletion level when moisture stress begins to decrease yields, and found that the relationship of continued depletion to reduced yields under stress conditions provides useful information for efficient management and use of water for crop production on irrigated land. Their results confirmed the general recommendation that 50 percent of plant available water can be depleted from major root zones of fine textured soils before significant yield reduction occur. Denmead and Shaw (6) studied the effects of soil moisture stress imposed at different stages of growth on the development and yield of corn. They found that moisture stress before silking, at silking, and after silking reduced yield by 25 percent, 50 percent, and 21 percent, respectively. They further found that the interactions between different growth stages were not statistically significant. The soil moisture stress used in their study represented the soil moisture content when it was depleted to the wilting point at certain stages of crop growth.

Soil water used by the plant varies with the plant-growth stage. Shaw et al. (26) related water use during different periods to yield, and found the highest correlation with yield was obtained during the period June 15 to August 1. Average daily use for this period was 0.18,

0.18, 0.15 inch, respectively. Water use by corn throughout the growing seasons was summarized by McKinney (15) who divided water use into nine 14-day periods. For the first period the water use was low, as the plants were emerging from the soil. Water use increased gradually during the next two periods as the corn plant developed in size. For the next four periods water use was highest because the corn was tasseling, silking, and developing kernels. A gradual decrease in water use was noted for the last two periods as the corn matured and the kernels dried. Letey and Peters (12) found that corn yields were closely related to the reserve soil moisture conditions at the beginning of the growing season and to the soil moisture stress to which the plant was subjected during the growing season. The moisture stress effect upon growth was found to be closely related to seasonal weather. Domingo and Robins (7) found that depletion in soil water to the wilting point level for one to two days reduced yields by 22 percent, while six to eight depletion periods reduced yield by 50 percent.

Soil moisture and soil structure are the most important factors upon which root depth depends. A study made by Long (14) on many crops, including corn, showed that a low fertility status in well-drained brown soils did not appear to hinder root development, and crop yields were higher than they were on poorly drained soils. Shaw and Laig (27) found that all of the water used by the corn plant came from the upper six inches of the soil up to June 14th. By June 27th all of the water used was from the top two feet, and by August 1, 10 percent of the water was being removed from depths of five to six feet. Long (14) found that the

growth of the plant above and below ground appeared to be related to the moisture content and degree of aeration of the soil.

The force with which a soil holds water, and the range between field capacity and wilting point, are related to the soil texture and slope position. Via (35) found that soils located at the base of slopes had wider moisture ranges than the surrounding soils on the slopes. The moisture available to plants in sandy soil is 5 percent by weight, or about one inch per foot of soil. This quantity is the difference between 9 percent moisture at field capacity and 4 percent at the permanent wilting point. Clay soils, by contrast, are capable of holding 14 percent, or 2.4 inches per foot, of available moisture. Consequently more rainfall is required for replenishment to field capacity of the fine textured soil than for a coarse textured soil. This water must also be applied at a slower rate because of low infiltration and percolation rates, but longer times will be required for plants to deplete the reserve.

Soil moisture changes throughout the year depending on climate and crop conditions. Rawls et al. (22) showed that maximum soil moisture accumulation occurred in late February at low elevations and in late May at the high elevations. Minimum soil moisture occurred in July and August. Maximum moisture accumulation varied from 8 to 18 inches. The depletion rate between minimum and maximum soil moisture was approximately linear, with a total depletion of 2.5 to 4 inches of water.

II. Occurrence of Soil Moisture Deficiency

Estimating the occurrence of soil moisture deficiency and excess by precipitation data for various time periods is inadequate since no allowance is made for antecedent precipitation, soil moisture storage, or rate of water loss through evapotranspiration. Van Bavel (30) defined agriculture drought on the basis of soil moisture conditions and resultant plant behavior. His definition for a drought day is a 24-hour period (starting at the time of the day at which the precipitation of the previous day is recorded) in which the soil moisture stress exceeds a limit which, based on experimental evidence, may be taken as a point at which the productive processes of the crop are being appreciably decreased. A drought day occurred whenever available soil moisture was depleted to a point critical for normal plant processes, as estimated from precipitation and evapotranspiration data by a moisture balance method. Barger and Thom (3) defined drought as a specific period of time during which the total amount of rainfall recorded at a station is deficient to the extent that, more often than not, crop yield falls below normal for the station under study. Safley (23) stated that rainfall has four fates: runoff, evaporation from soil and/or plant surface, transpiration, and deep percolation. Of these, only evaporation and transpiration comprise water which is primarily related to plant growth.

Evapotranspiration (ET), or consumptive use, is the removal of water from a unit area during a specified time by evaporation from the

or plant surface and by transpiration from plants. Schwab et al. (25) described several methods for predicting evapotranspiration rate; among them are the empirical methods which have been developed with the assumption that the energy available for evaporation is proportional to the temperature.

In 1948 Thornthwaite (28) presented a method which may be used to predict evapotranspiration from climatic data. The parameters used in the method are temperature and length of day. The formula developed by Thornthwaite is:

$$E = C T_m^a$$

in which E = potential evapotranspiration, cm;

C = a coefficient depending upon location;

T_m = mean monthly temperature, $^{\circ}\text{C}$ and

a = exponent.

The exponent a can be evaluated in terms of the annual heat index I as follows:

$$a = 67.5 \times 10^{-8} I^3 - 77.1 \times 10^{-6} I^2 + 0.0179 I + 0.492,$$

in which

I = heat index;

$$I = \sum_{m=1}^{12} \left(\frac{T_m}{5} \right)^{1.51}.$$

Penman (20) found that energy changes are the same for all areas under the same climatic conditions if the plant cover is complete and water is available, regardless of the soil or plant. The parameters used

in this method to estimate the amount of evaporation are mean temperature, mean air vapor pressure, mean wind velocity and mean sunshine hours.

Penman also found this estimate to be useful in predicting ET rates and water content of the soil if it were adjusted for soil water supply as estimated by spring rainfall. Penman showed that this could be accomplished by utilizing the functional equation in the form:

$$E = f(u) (e_o - e_a)$$

$$K = \gamma f' (u) (T_o - T_a)$$

in which $f(u)$, $f'(u)$ = functions of wind speed;

e_o = saturated vapour pressure of water;

t_o = surface temperature;

e_a = actual vapour pressure of the air;

T_a = mean air temperature; and

γ = constant to keep units consistent.

The Penman method could be used to provide estimates of potential evapotranspiration (PE), which is the maximum amount of water a plant will use assuming the supply to be nonlimiting. He also suggested a crop factor to be applied to free surface evaporation estimates to predict seasonal evapotranspiration.

In 1950 Blaney and Criddle (4) developed a simplified formula for estimating consumptive use in the arid western regions of the United States. It is assumed that the heat budget is shared in fixed proportion between heating the air and evaporation. With such an

assumption it is clear that consumptive use should be related to hours of sunshine and temperature. In their method, monthly consumptive use (CU), is computed by the equation:

$$CU = \frac{k T_m P}{100}$$

in which k = average seasonal consumptive use coefficient selected for different crops and length of growing season;

T_m = mean monthly temperature; and

P = monthly percent of annual daytime hours.

Hargreaves (8) also developed an equation for estimating potential evapotranspiration. The elements used for computation include mean air temperature and some form of radiation and/or day length. Other elements are of relatively minor importance in locations of low elevation. For these locations the simple equation is:

$$P E T = MF \times T$$

where $P E T$ = potential evapotranspiration, mm;

MF = monthly evapotranspiration factor, mm; and

T = mean temperature, degrees Fahrenheit.

Van Bavel (30) developed a first approximation to calculate drought occurrence using past rainfall records and an estimate of evapotranspiration. He proposed that the incidence of drought be characterized by determining the number of days during the growing season in which soil moisture tension exceeds a value which is known to appreciably impede crop growth. The frequency of these drought days depends on the

rainfall pattern, moisture characteristic of the soil, root depth, physiological reaction of the plant to moisture tension, and rate of evapotranspiration. The proposed drought criterion reflects the differences in moisture characteristics of different soils, in depth of rooting, and in drought tolerance of the plant. Van Bavel further reported that the results obtained may be used to determine the need for supplemental irrigation and the safe size of storage reservoirs for a given location, crop, and soil. Adebayo and Harris (1) found that the soil moisture tension at which the crop growth appreciably decreased varied with soil type, and the growth rate starts to decrease between five to three bars water potential in the soil.

Safley (23) showed that crop yield variation was most sensitive to drought as calculated by using Thornthwaite-derived evapotranspiration values. Crop response to drought derived by the Blaney-Criddle method was intermediate, while the response to Penman-derived values indicated that the latter method was least sensitive to prevailing conditions. Holmes and Robertson (9) investigated evapotranspiration in a growth chamber. The results showed that actual evapotranspiration occurred at a potential rate during the initial period when the soil was near field capacity. After the soil moisture was depleted to a point where the ability of the soil to transmit moisture was reduced, the actual rate of evapotranspiration was sharply reduced. Evapotranspiration continued to diminish approximately exponentially as the soil dried further.

Pierce (21) used lysimeters to measure water losses. His procedure involved the use of potential evapotranspiration determined by empirical

methods. He multiplied potential evapotranspiration by factors for crop stage, soil dryness, and rainy days to compute water loss from soil. The soil dryness correction factor had a value of 1.0 for an initial period and reduced as soil moisture depleted further. Denmead and Shaw (6) studied transpiration from corn under field conditions in Iowa. They observed that actual transpiration took place at the potential rate for some time as the soil moisture was depleted below field capacity. The point at which the ratio of actual-to-potential transpiration dropped below 1.0 was found to be a function of the potential value itself. On a day when the potential for transpiration as determined by meteorological conditions was low, actual transpiration occurred at this potential rate even though soil moisture was near the permanent wilting point. However, on a day when the potential for transpiration was very high, the actual rate dropped below the potential rate when the soil moisture was only slightly below field capacity.

Different models have been used to determine soil moisture deficiency. The common components used in these models were evatranspiration rate, precipitation, water holding capacity of the soil, runoff, and percolation. Jensen et al. (10) used a model which included climate, crop, and soil data. The major dependent variable in the model is soil moisture depletion. The model is:

$$D = \sum_{i=1}^n (Et - Re - I + Wd);$$

where D is the depletion of soil moisture, Et is evapotranspiration, Re is rainfall (excluding runoff), I is irrigation water applied, Wd is

the drainage from the root zone, and $i = 1$ for the first day after a thorough irrigation when $D = 0$. The above model was used for scheduling irrigation. Wiser and van Schilfgaarde (37) developed a water balance method for estimation of soil moisture status. They considered the soil profile as layers with different water holding capacities and depletion rates, assuming that the moisture supplied by precipitation moves down through the soil layers only if the layer above the layer of percolation is at field capacity. Daily ET is obtained from PE by using the relation $ET = PE (SMC_{t-1}/SMC)$, where ET is the corrected daily evapotranspiration, SMC_{t-1} is soil moisture of the layer at the end of the previous day and MSC is the total storage capacity of the same layer. Ligon et al. (13) developed a procedure for estimating occurrence of soil moisture deficiency and excess. The procedure includes the use of a soil moisture balance model utilizing as input data generally available climatological data. Special attention was given to the relationship between soil moisture level and rate of transpiration. The moisture balance involves available moisture storage in two soil layers, and incorporates an evapotranspiration correction based on the moisture level in each of these layers. The soil moisture balance was given limited checking by comparing computed and measured soil moisture under bluegrass sod and by comparing computed moisture excess with measured streamflow. Wiser (35) developed a soil moisture balance procedure which incorporates up to three soil layers to account for the partial penetration of precipitation into a dry soil profile, as well as rapid evapotranspiration.

Palmer (19) estimated the occurrence of meteorological drought. His method included a soil moisture balance involving essentially the same principle used by Holmes and Robertson (9). Thorthwaite and Mather (29) determined the water surplus, water deficit, soil moisture storage, and water runoff from comparison of the seasonal march of precipitation with evapotranspiration. Van Bavel (31) found that in the lower Mississippi Valley area the occurrence of drought depends markedly on the storage capacity of the soil for water; and the moisture excess occurs primarily during the winter and early spring months and is only slightly influenced by moisture storage capacity of the soil. A similar study made by Van Bavel (32,33,34) in Georgia, South Carolina, and Virginia evaluated the drought hazard in terms of soil moisture and acceptable odds. Safley and Parks (24) determined probabilities of agricultural drought in Tennessee using daily rainfall and temperature data for many years. They evaluated water use models in relation to crop yields. The model used in their calculations was:

$$SMS_i = SMS_{i-1} - PE + (P - RD)$$

where SMS_i is the current soil moisture status, SMS_{i-1} is the soil moisture status of the previous day, PE is the amount of calculated evapotranspiration for that day, P is the precipitation, and RD is runoff loss from the system. Precipitation in excess of available soil storage was considered lost from the system by runoff. When the soil moisture status reaches 0 inch, a drought-day occurs.

CHAPTER III

PROCEDURE

I. Soil Moisture and Crop Yield

A. Site Selection

A field on the University of Tennessee Holston Farm near Knoxville was selected for this study. The field, which contains approximately 12 acres, was chosen because of its potential need for both irrigation and drainage. The entire field was in corn during the course of the study. A topographic survey was made of the field by use of the grid method, and a topographic map (Figure 1) was prepared.

Soil moisture access tubes were located in three soil mapping units as shown in Figure 1. The soil mapping units are: Altavista loam (2B), 2 to 5 percent slope; Lindside silt loam (19); and Huntington silt loam (4), 0 to 2 percent slope.

B. Data Collection

1. Equipment installation. Soil moisture access tubes were installed in April, 1976, at five locations chosen by inspection to represent soil moisture distribution over the field. The tubes were installed at 100-foot grid points in patterns as indicated in Figure 1.

The access tubes were installed to a depth of three feet. Soil from each tube location was saved for subsequent mechanical analysis. Each tube, cut from two-inch aluminum irrigation pipe, was positioned so that

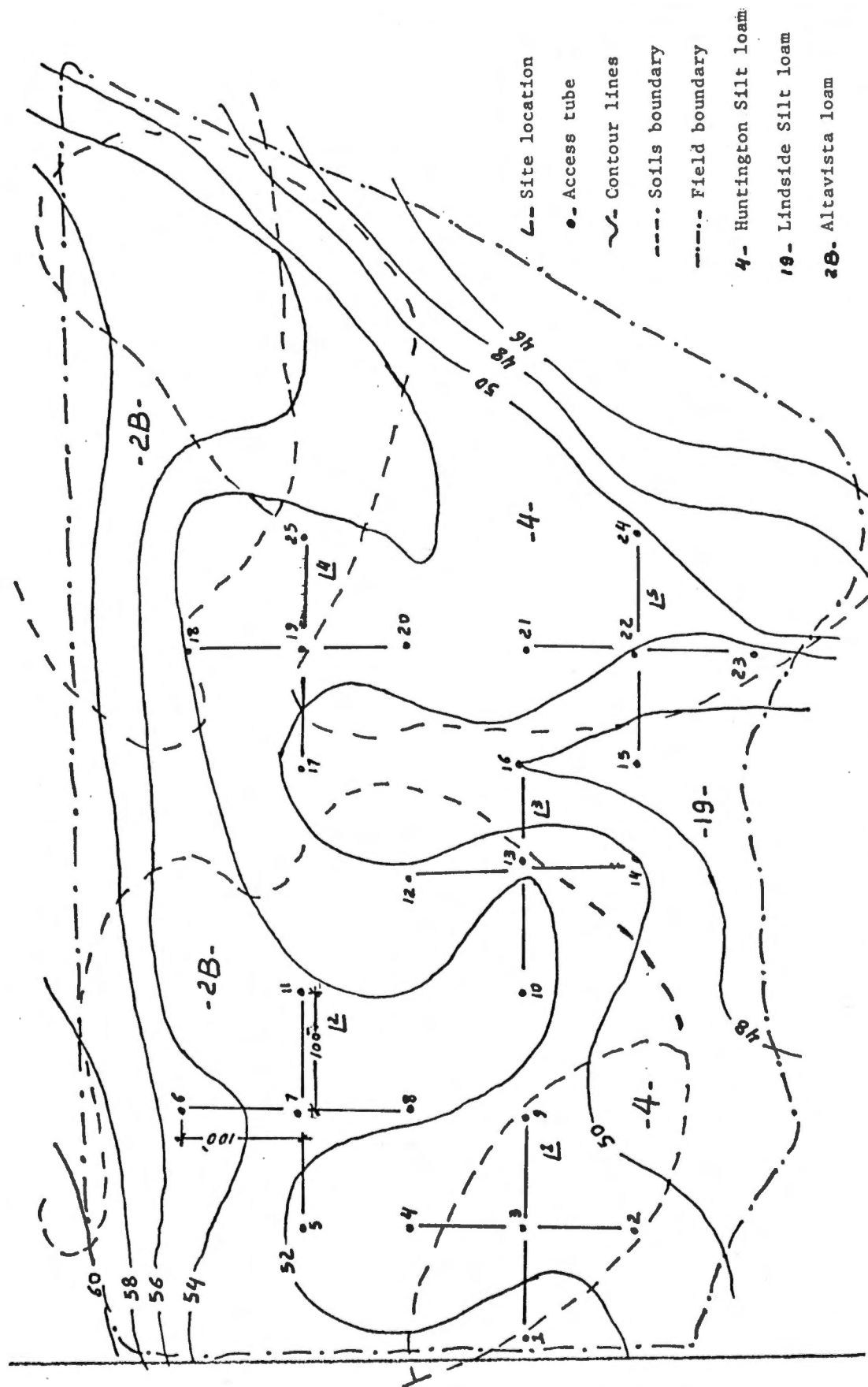


Figure 1. Location of soil moisture access tubes with respect to soil and topography.

the end of the tube was six inches above the soil surface. A number 10-1/2 rubber stopper was placed in the lower end of the tube to prevent water from entering the tube. The tops of the tubes were closed with rubber stoppers to prevent rainfall from entering. Soil was packed around each tube to prevent excessive vertical water movement.

A standard rain gage and a recording rain gage were installed at the edge of the field, and these were monitored on a weekly basis during the growing season.

2. Soil moisture measurements. Neutron scattering equipment consisting of a subsurface moisture probe and a scaler was used for moisture measurements. Soil moisture measurements were made at approximately weekly intervals beginning on May 14, 1976. Measurements were made at depths of 6, 12, 18, 24 and 36 inches.

3. Soil analysis. The soil physical properties included in this study were made as follows: mechanical analysis by the pipette method, field capacity by the porous method, wilting point by the pressure membrane method, and bulk density by the core sample method.

A composite soil sample was prepared for each of the five locations by blending the soil removed from each of the five tubes within the location. Each of the 25 samples were crushed, and then sieved through 2-mm wire mesh. This procedure was followed for samples taken at 6-inch, 18-inch, and 36-inch depth intervals.

Soil analysis obtained by the pipette method consisted of percent sand, coarser silt, silt, and clay. The percent moisture (dry weight

basis) remaining in the soil after being placed on the porous plate under pressure of five pounds per square inch ($1/3$ atmosphere) was the soil moisture content at field capacity. The percent moisture remaining in the soil after being placed on the pressure membrane under a pressure of 220 pounds per square inch (15 atmosphere) was the soil moisture content at wilting point. The values obtained were then converted to a volume basis. Bulk density values were obtained by dividing the weight of the dry core soil sample by the cylinder volume.

4. Crop yield. Corn was planted on May 1, 1976, and samples were harvested on August 10. Crop yield (pound per acre green matter) was determined by hand harvesting and weighing all plants from a 30-foot row segment at each access tube.

C. Data Analysis

Soil moisture values (percent by volume) within soil types were averaged and plotted against the time of observation for 12-inch and 24-inch depths. Eight tubes were located on Huntington silt loam, nine tubes were located on Altavista loam and eight tubes were located on Lindside silt loam. This analysis served as a basis for comparing soil moisture variation among soil types. The same procedure was followed in relating soil moisture to elevation range.

Maximum and minimum moisture values for the 12-inch depth and the 24-inch depth were selected from sites located within the same soil type and the same elevation range and subsequently plotted against yield values. This was done for three one-month periods during the corn-growing season.

II. Occurrence of Soil Moisture Deficiency

A soil-moisture balance procedure similar to Van Bavel's procedure of predicting drought days was used to determine the occurrence of soil moisture deficit days during the corn growing season. A soil-moisture deficiency day was defined as a 24-hour period in which the soil moisture stress exceeded a point at which the productive processes of the crop are being appreciably decreased. An average rooting depth was assumed to be 24 inches and a limiting soil moisture tension was assumed to be four bars tension. Potential evapotranspiration was estimated with Thornthwaite's formula as given in Chapter II. Monthly values were computed using average air temperature values for the period of study.

Soil moisture was assumed to be at field capacity on May 1, the first day of the period under study. Subsequently, the pertinent evapotranspiration was subtracted and precipitation was added for each day. An exception to this procedure was that a higher storage value than that between field capacity and growth-limiting soil tension was not allowed. Also, when the result of the daily calculation was zero or negative no subtraction was made for evapotranspiration on subsequent days. The days on which the storage value was zero or negative were defined as soil moisture deficit days.

CHAPTER IV

RESULTS AND DISCUSSION

I. Soil Moisture within Soil Types

Average soil moisture among all sites within each soil type for the growing season was determined for the 12-inch depth and the 24-inch depth. Figure 2 shows that Lindside soil had the highest moisture content in both the 12-inch and the 24-inch profiles, followed by Altavista and Huntington soils, respectively.

Differences in moisture content among soil types in the 12-inch profile were greater than in the 24-inch profile. This was due to the higher percentage of clay content at the 12-24-inch depth. Mechanical analysis of the composite soil samples are presented in Table A-2 (Appendix), and bulk densities at the 6- and 18-inch depths are presented in Table A-3 (Appendix). The percentage of sand decreased as depth increased. Tables A-4 and A-5 (Appendix) show the percent moisture at field capacity and wilting point, respectively.

The Altavista soil had a maximum of 2.4 inches water within the 12-inch profile (Figure 2), while Lindside had a maximum of 1.54 inches within the same depth zone. These values occurred on May 30. Field observation indicated that the corn growth rate was reduced by the above high levels of soil moisture. On the last week of May, Lindside soil had 5.2 inches of water in the 24-inch profile. Altavista soil had 4.15 inches of water in the 24-inch profile on July 30. Variation in the

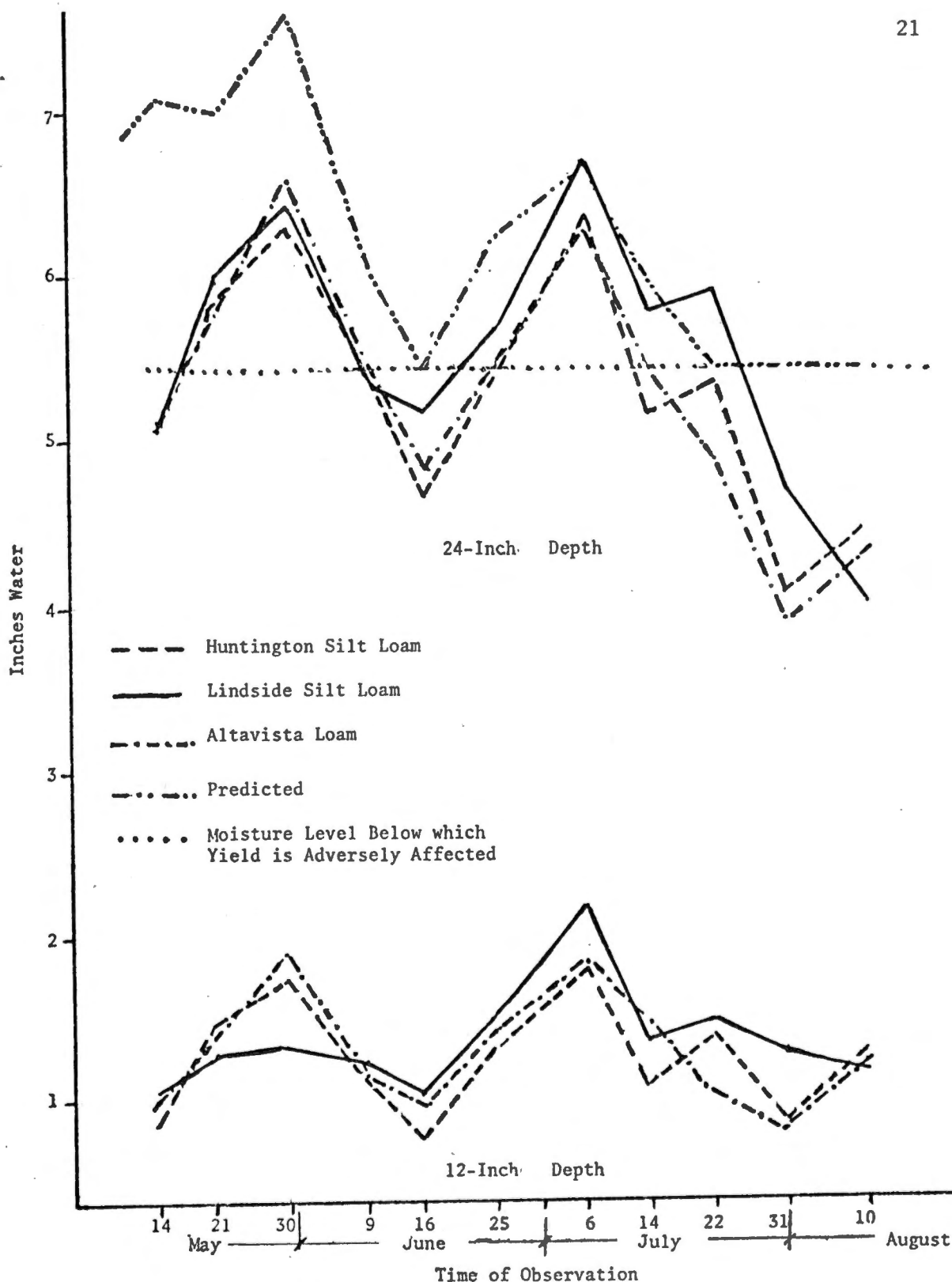


Figure 2. Seasonal soil moisture distribution within the profile of three soils.

moisture range among the three types of soil was small during the growing season, but on May 30 the Altavista soil contained 0.6 inches more water in the 12-inch profile than the Lindsides soil. This difference could be the reason for the reduction in the average yield on Altavista soil. On June 16, the moisture content in Huntington soil was only 1.0 inch in the 12-inch profile (Figure 2). Crop yield was not adversely affected, however, probably because stress conditions had short durations.

II. Soil Moisture Variation among Elevation Ranges

The 25 moisture access tubes were distributed among three elevation ranges as follows: 48-50 feet (5), 50-52 feet (13), and 52-54 feet (7). The average seasonal soil moisture for each elevation range is shown in Figures 3 and 4 for the 12-inch and the 24-inch profile, respectively. The figures show that the lowest elevation range had the highest soil moisture content for both depths. In the 48-50 feet elevation range the maximum soil moisture was 3.2 inches in the 24-inch profile, while it was 1.6 inches in the 12-inch profile. On June 15, soil moisture in the 24-inch profile was below 5.7 inches for the 50-52 feet and 52-54 elevation ranges. This level of soil moisture represents 4-bars tension, which is sufficiently low to adversely affect yield. The soil moisture level for the 48-50 feet elevation range was within the range of available water holding capacity of the soil except for August 10, when it was 4.25 inches. There was an average difference of +1.4 inches water between the 48-50 feet and 52-54 feet elevation range

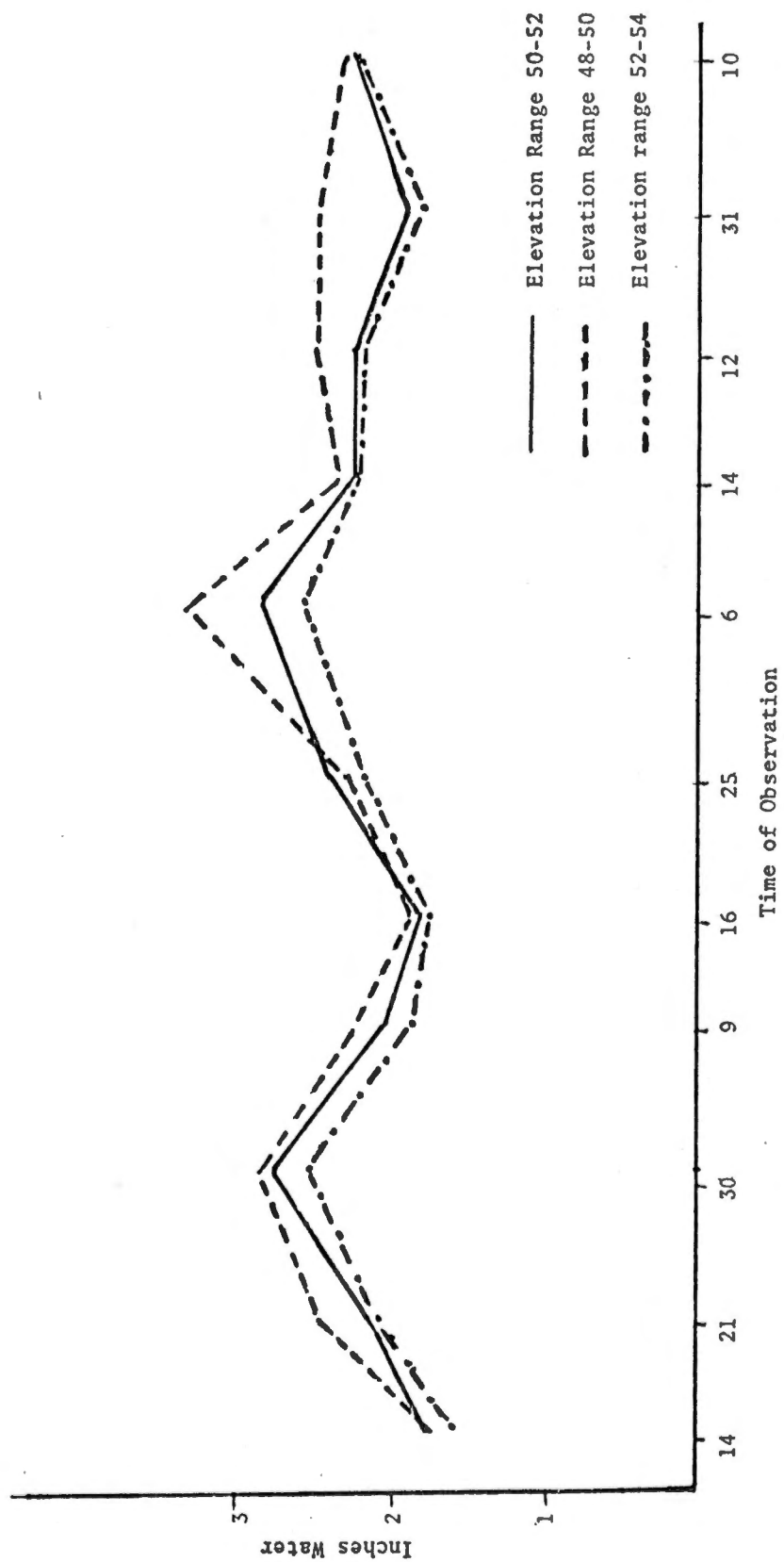


Figure 3. Seasonal soil moisture (0-12 inch depth) distribution by elevation range.

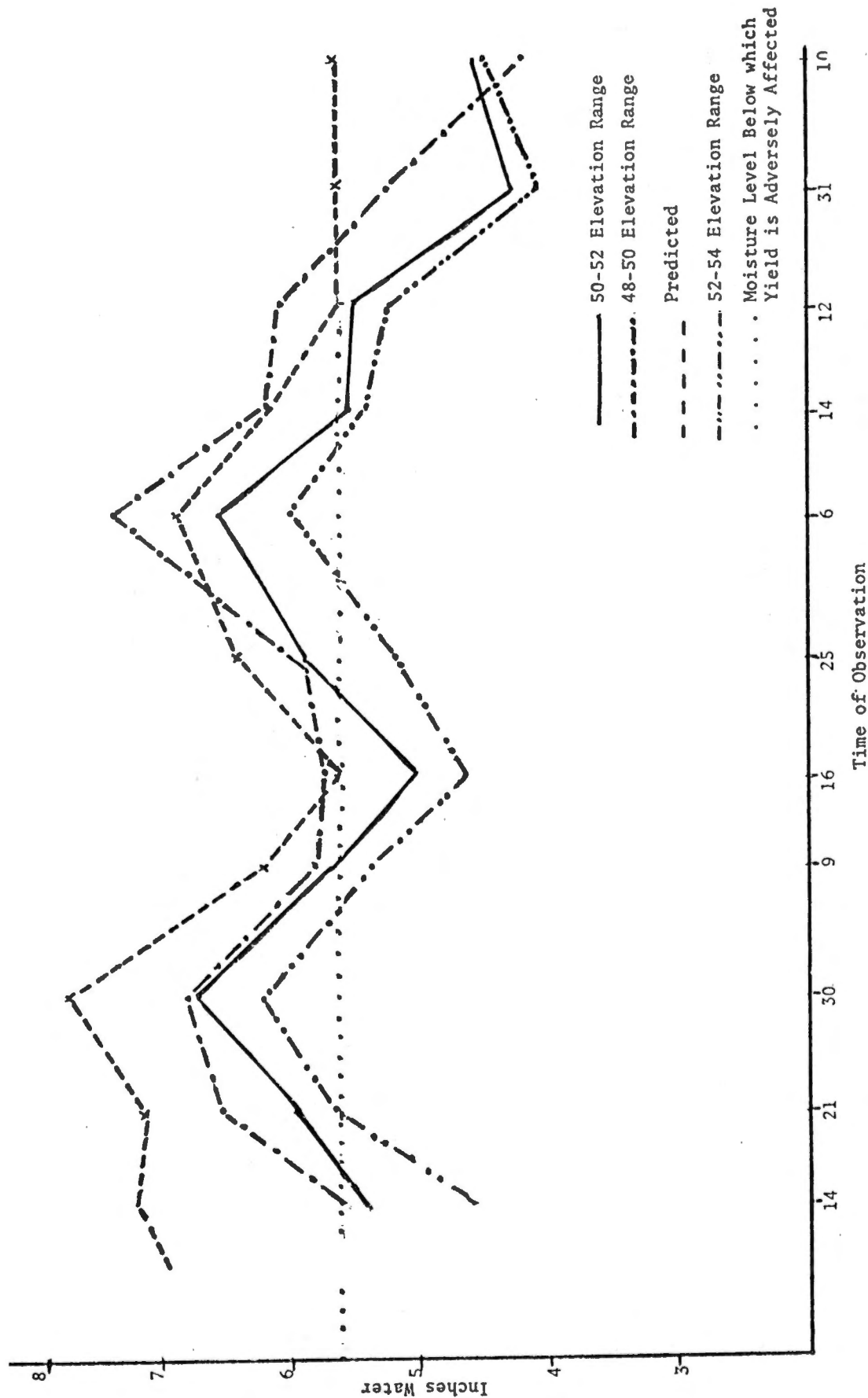


Figure 4. Seasonal soil moisture (0-24 inch depth) distribution by elevation range.

in the 24-inch profile. This difference was due to the poor drainage existing at the lower elevation range.

III. Effect of Soil Moisture on Crop Yield

Moisture range is defined as the minimum and the maximum values of the observed soil moisture at a single tube from May 14 to August 10, 1976. Sites within the same elevation range and the same soil type (Table 1) but with different yields were selected for yield comparison. Corn yield within each soil type and elevation range is presented in Figures 5 and 6, respectively. The growing season was divided into the three periods, May 14 through June 13, June 14 through July 13, and July 14 through August 13. Table A-1 shows the yield, the elevation range and the soil type for each site.

Observed soil moisture for three periods of the growing season at sites 4 and 12 located on Altavista loam is shown in Figure 7. The maximum and minimum soil moisture exceeded field capacity at site 4 for the first and second periods of the growing season. Maximum soil moisture exceeded field capacity at site 12 for the first and second periods. Wilting point was reached in the 12-inch profile for the three periods of the growing season at both sites. Site 12 was located in a sloping area; consequently site 4 retained more precipitation than site 12 and the soil moisture increased in the soil profile. This level of soil moisture probably caused the yield at site 4 to be less than at site 12.

TABLE 1
SITES WITHIN A SOIL TYPE AND ELEVATION RANGE

Elevation Range	Soil Type	Tubes
48-50	19	15, 16, 17 ^a
	4	22, 23
50-52	19	14, 18, 19, 25
	4	2, 3, 9, 20, 21, 24
	2B	4, 5, 12 ^b
52-54	2B	6, 7, 8, 10, 11, 13
	19	1

^aHad the lowest yield.

^bHad the highest yield.

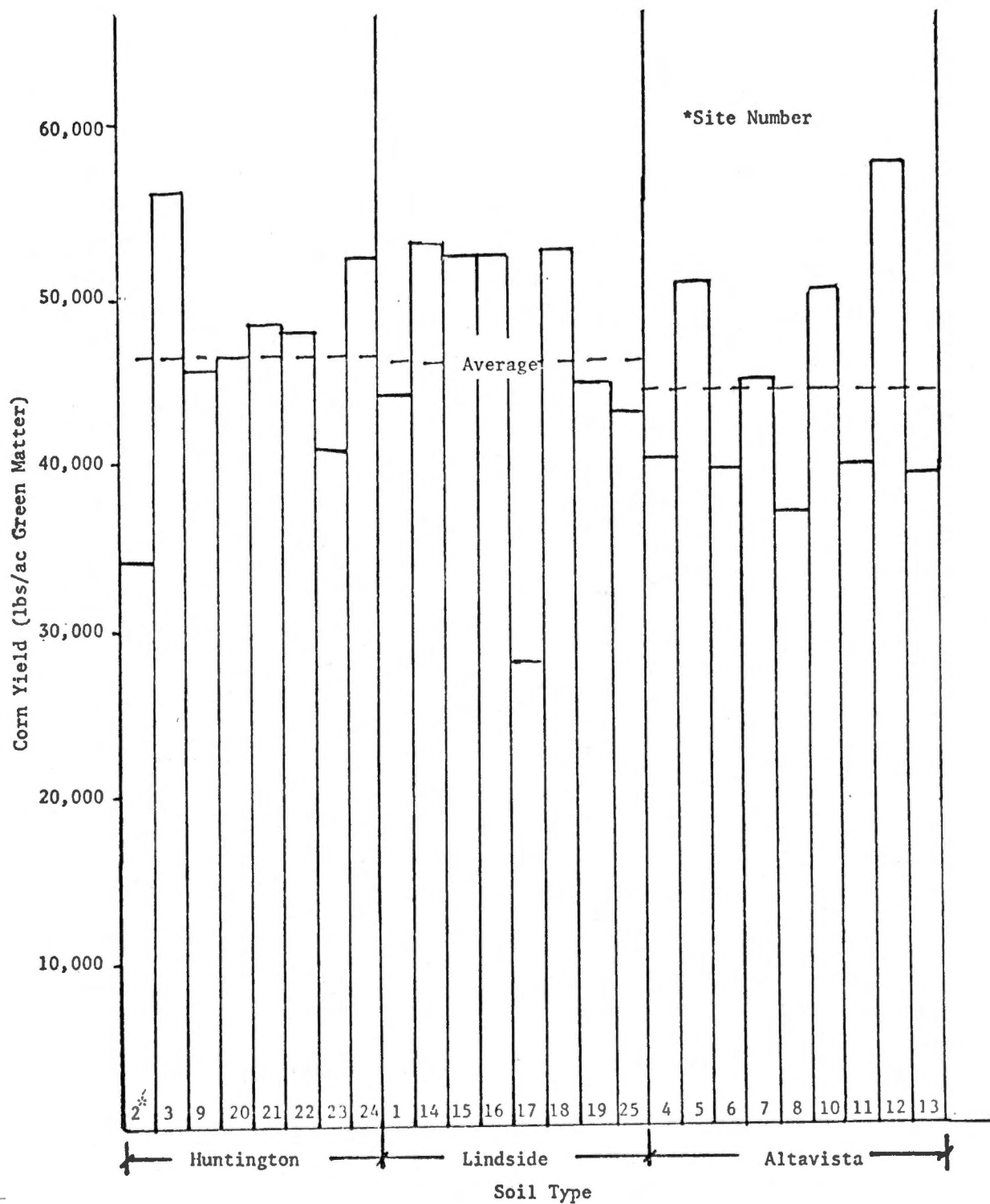


Figure 5. Corn yield by soil type.

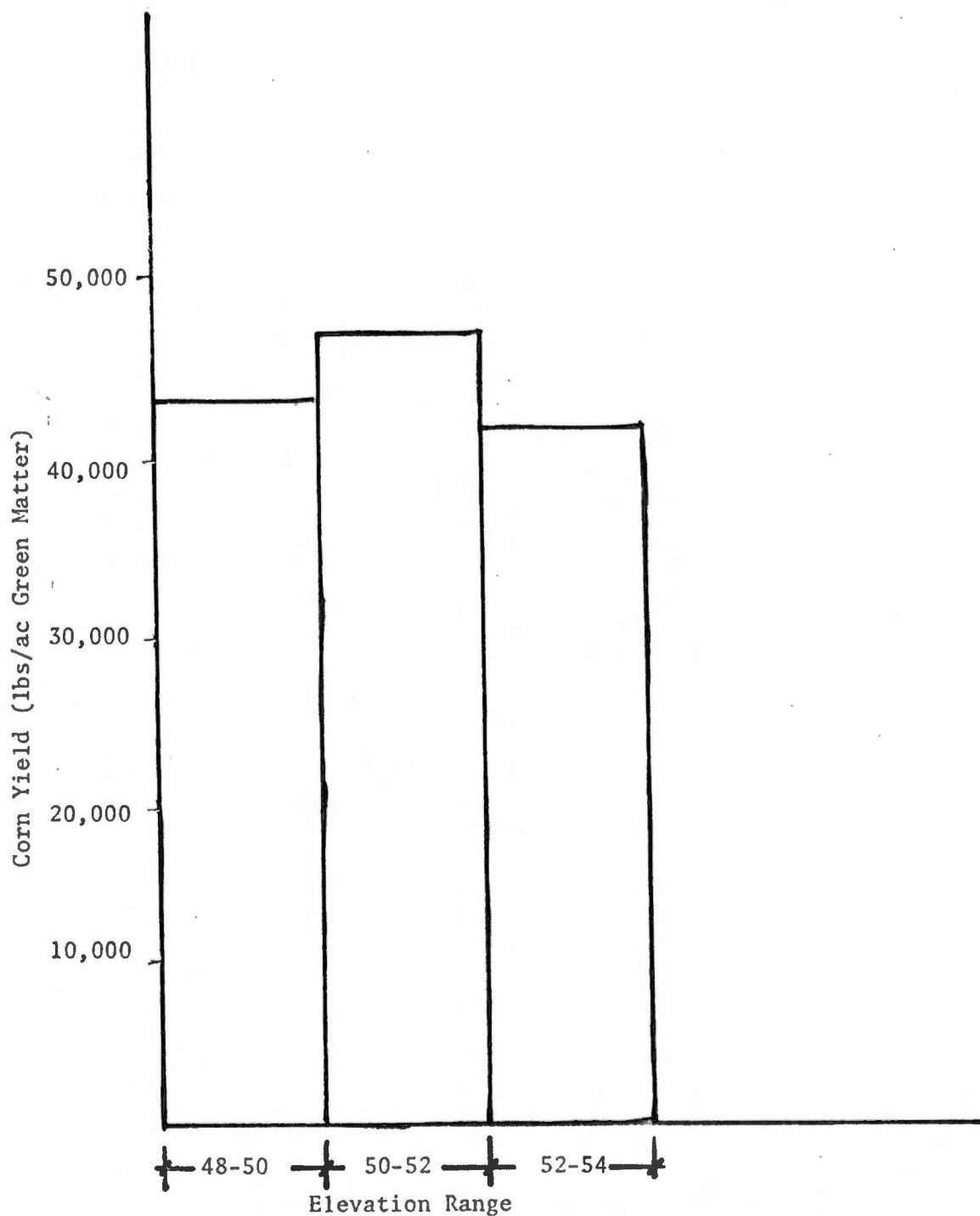


Figure 6. Average corn yield by elevation range.

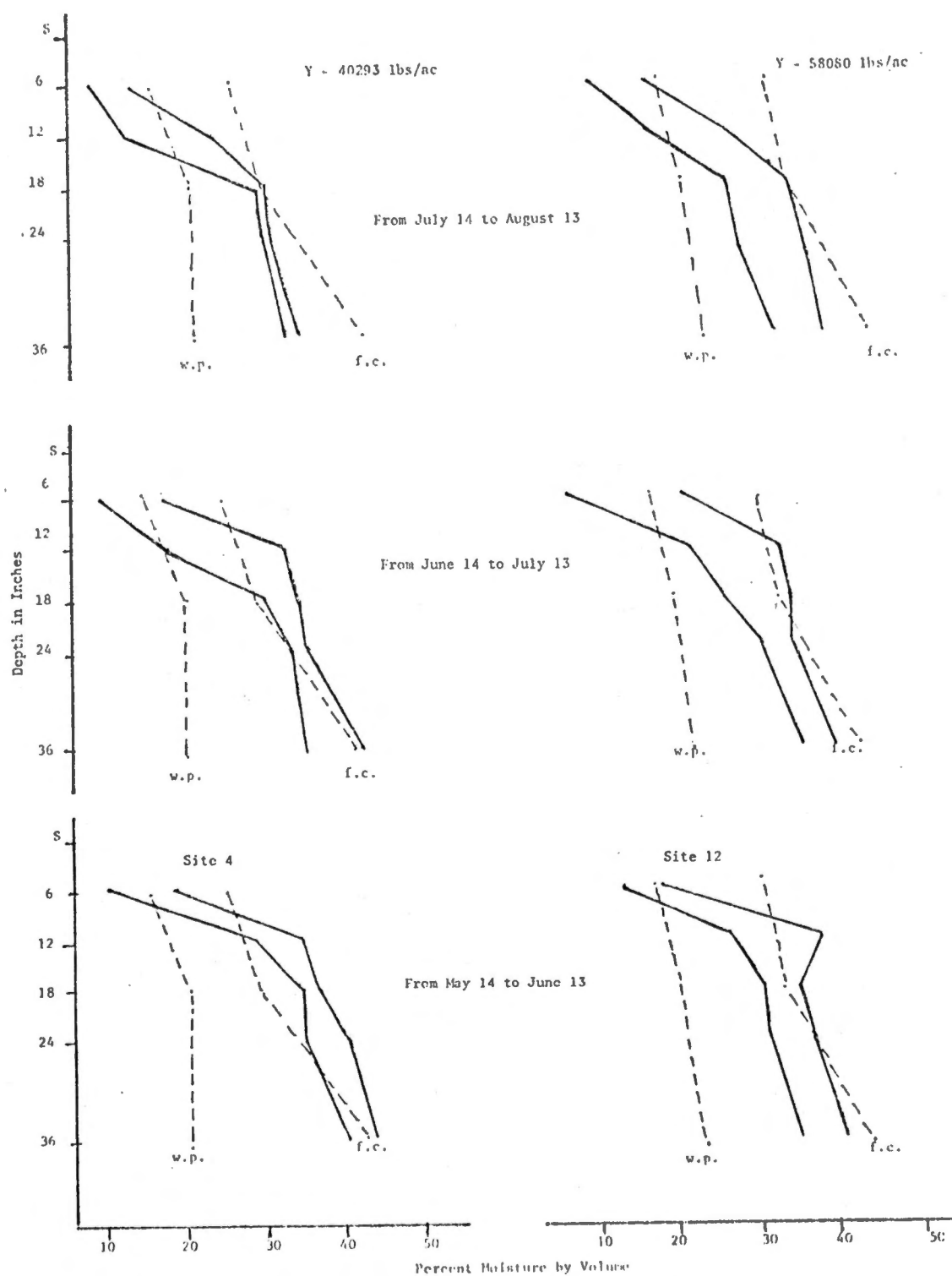


Figure 7. Range of average observed soil moisture at sites 4 and 12.

Observed soil moisture for three periods of the growing season at sites 16 and 17 located on Lindside silt loam is shown in Figure 8. The maximum soil moisture at site 17 exceeded field capacity for the first and the second periods of the growing season. In the third period of the growing season the soil moisture range was within the available soil moisture, except that the wilting point was reached in the 18-inch profile. The maximum soil moisture exceeded field capacity at site 16 for the first period of the growing season, but this level of soil moisture did not effect the yield at this site, probably because the root system of the plant was within the upper few inches of the soil during this period of the growing season. Site 16 was located in a natural waterway which passes through the field, but no water accumulated on the area. The low yield at site 17 was due to ponding over the area, resulting in an excessively high level of soil moisture.

Figures of soil moisture variation and crop yields for the remainder of the sites are presented in Appendix B.

IV. Soil Moisture Deficiency

Calculation of soil moisture deficiency days was made using a soil-moisture balance procedure for the corn-growing season. Table A-7 (Appendix) shows the equivalent water depth at 4-bars tension, wilting point and field capacity for three depth zones. The monthly potential evapotranspiration rate is presented in Table A-8 (Appendix). A maximum water holding capacity of 2.27 inches was assumed for the first day of the growing season.

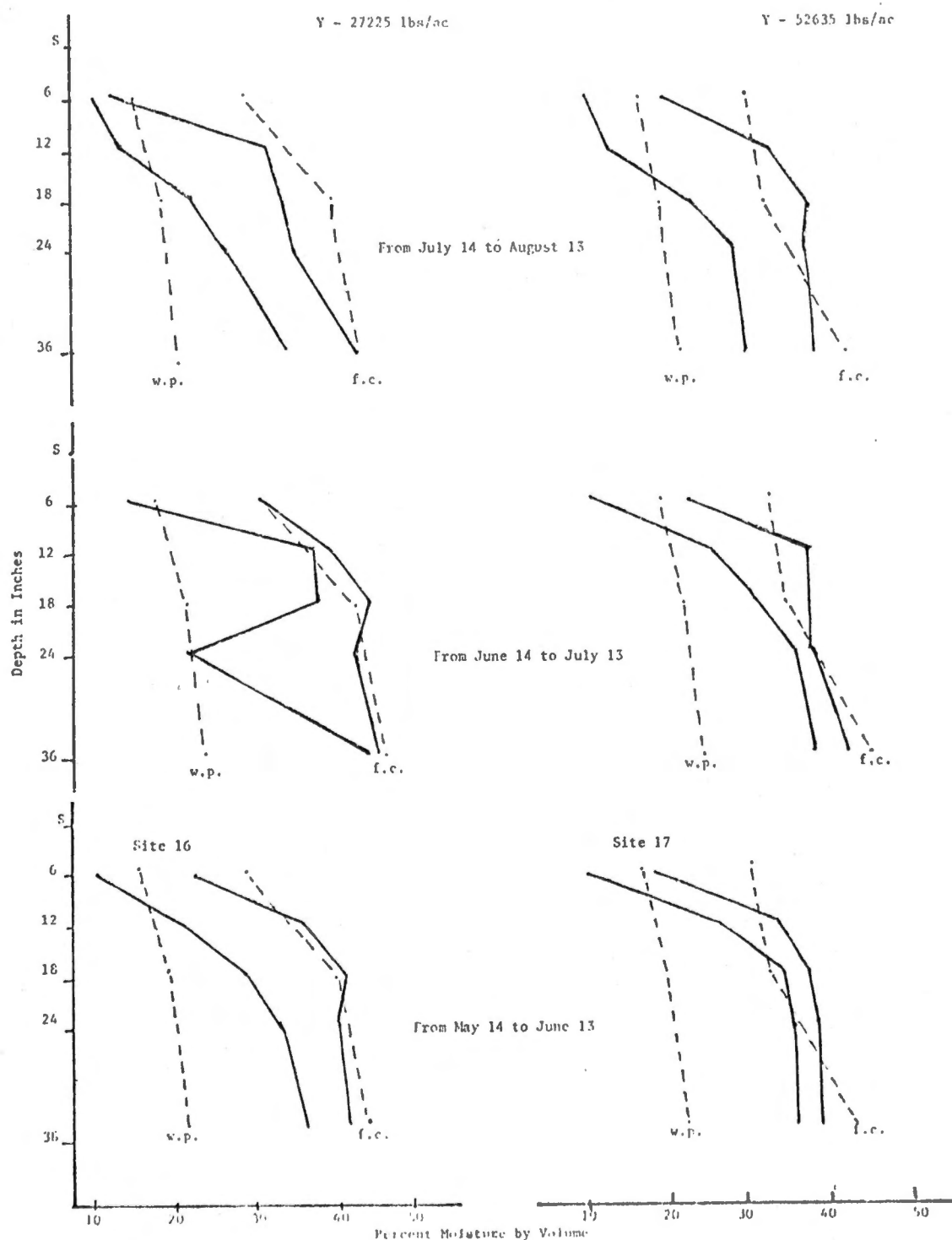


Figure 8. Range of average observed soil moisture at sites 16 and 17.

The predicted soil moisture appeared to be close to the measured soil moisture in Lindside silt loam most of the growing season. However, predicted soil moisture was greater than the measured value by 1.7 inches on May 14 (Figure 2, p. 21). The assumption that field capacity existed on the first day of the water-balance procedure was the main reason for the difference between the predicted and the measured soil moisture. Actually the soil moisture at that time was less than the assumed value. No attempt was made to compare the predicted and measured values of soil moisture in the 12-inch profile.

Total recorded precipitation for the growing-season period was 1.6 inches above the normal (Table 2). Soil moisture was affected by rainfall level during the month of May, in which precipitation was 2.28 inches above normal. This high level of precipitation probably reduced the effect of soil type on crop yield. Predicted and measured soil moisture compared better within elevation ranges than within soil types. On May 14 predicted soil moisture was 1.20 inches, 1.35 inches, and 2.30 inches more than the measured soil moisture in the 48-50, 40-52 and 52-54 feet elevation range, respectively. Predicted soil moisture was close to measured soil moisture in the 48-50 feet elevation range because the assumed water holding capacity at the first day of the growing season was more than the actual soil moisture on that day. Predicted soil moisture was less than measured soil moisture on July 6 by 0.25 inches due to precipitation which occurred on July 4 (Figure 4, p. 24). A total of 20 soil moisture deficit days were predicted, while 42 soil moisture deficit days were observed. However, the frequency of

TABLE 2
NORMAL PRECIPITATION AND 1976 PRECIPITATION
FOR THE GROWING SEASON

Month	1976 Precipitation (inches)	29-Year Normal Precipitation (inches)	Inches below Normal	Inches above Normal
May	5.56	3.28	--	2.28
June	3.46	3.63	0.17	--
July	3.65	4.70	1.05	--
August	3.78	3.24	--	0.54
Total	16.45	14.85	--	1.60

the observed soil moisture deficit days did not create stress condition in the soil.

An analysis of variance was applied to the corn yield data for the three months of the growing season. Table A-6 (Appendix) shows average moisture content, elevation range and yield at each site for the month of July. The average soil moisture level in the month of July correlated with the yield better than that in May or June. The results of the analysis of variance for the month of July are given in Table 3. This analysis indicated that the average soil moisture levels among different elevation ranges did not significantly relate to the corn yield. The weak correlation between moisture level and corn yield was probably due to the season precipitation being 1.6 inches above normal for this year of study.

Regression analysis was also applied to the yield data for the three months of the growing season. The yield prediction equations for average soil moisture for the month of July and for the three elevation ranges are:

Elevation range 48-50, $Y = 64442 - 2995.7M$;

Elevation range 50-52, $Y = 64929 - 2995.7M$;

Elevation range 52-54, $Y = 57530 - 2995.7M$;

where Y = average yield, lbs/ac green matter, and

M = soil moisture content, inches equivalent.

The negative sign of the regression coefficient implies that the yield is inversely proportional to the moisture content. Soil moisture levels were near the field capacity throughout the soil profile because

TABLE 3
ANALYSIS OF VARIANCE FOR CORN SILAGE YIELDS
FOR THE MONTH OF JULY

Source	Degree of Freedom	Mean Squares	F
Elevation range/moisture	2	105,971,516	2.16*
Moisture/elevation range	1	95,328,112	1.94*
Residual	4	49,049,129	

*Not significant at the 0.05 level of probability.

the precipitation level was above normal in this year of study.

However, corn yield was not adversely affected by this high level of soil moisture.

CHAPTER V

SUMMARY AND CONCLUSIONS

The objectives of this study were (1) to determine the effects of soil moisture variation due to topography and soil type, (2) to determine the effect of soil moisture variation on corn yield, and (3) to compare observed soil moisture deficiency occurrences with those predicted by using a soil-moisture balance procedure. Twenty-five soil moisture access tubes were installed throughout a 12-acre corn field after April 30, 1976, on which date the corn was planted. Weekly moisture measurements were made during the growing season. Corn yield (green weight basis) was determined on August 10, 1976.

Based on the results of this one-year study, the following conclusions were reached:

1. The influences of soil type and elevation range on yield were not significant in this year of study probably because precipitation level was 1.6 inches above normal during the growing season;
2. Corn yield increased as moisture content approached field capacity throughout the soil profile;
3. Soil moisture was greater in sites located on level ground where frequent ponding occurred;
4. The predicted and measured soil moisture were in close agreement except during the first month of the growing season.

5. Soil moisture deficiency occurred in the upper foot of the soil profile, while moisture excess occurred at depths of two and three feet.
6. A total of 20 soil moisture deficit days were predicted, while 42 soil moisture days were observed.

Lindsite silt loam had the highest average soil moisture, followed by Altavista loam and Huntington silt loam, in that order. Soil moisture differences among soil type had little effect on corn yield, probably because of the above normal precipitation during the growing season. Water ponding on low areas contributed to increasing the soil moisture level.

This study was limited to a relatively small field with few soil types, one crop, and one growing season. Land grading of the field area would eliminate the ponding of water over the level areas and give better moisture distribution over the field.

Further study is recommended to determine soil moisture variation among soils of larger areas and over a wider range of climatic conditions and growing seasons.

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LITERATURE CITED

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APPENDIXES

APPENDIX A

TABLE A-1

YIELD OF CORN (GREEN MATTER) FOR 25 SITES BY SOIL TYPE
AND CONTOUR ELEVATION RANGE

Site	Soil Type*	Elevation Range	Yield (lbs./ac.)
1	19	52-54	44,286
2	4	50-52	34,364
3	4	50-52	56,507
4	2B	50-52	40,293
5	2B	50-52	51,062
6	2B	52-54	39,688
7	2B	52-54	45,012
8	2B	52-54	37,147
9	4	50-52	45,980
10	2B	52-54	50,578
11	2B	52-54	39,930
12	2B	50-52	58,080
13	2B	52-54	39,325
14	19	50-52	53,240
15	19	48-50	52,635
16	19	48-50	52,756
17	19	48-50	27,225
18	19	50-52	52,998
19	19	50-52	45,012
20	4	50-52	46,706
21	4	50-52	48,642
22	4	48-50	48,158
23	4	48-50	41,140
24	4	50-52	52,635
25	19	50-52	43,076

*Soil type (4) is Huntington silt-loam, 0-3 percent slope.

Soil type (19) is Lindsides silt-loam.

Soil type (2B) is Altavista loam, 2-5 percent slope.

TABLE A-2
MECHANICAL ANALYSIS OF SOIL BY PIPETTE METHOD

Depth in Inches	Composite Sample Number	Percent Sand	Percent Silt	Percent Clay	Percent Coarse Silt
6	1	14.9	36	28	21.1
	2	18.5	36	28	17.5
	3	12.0	20	40	28.0
	4	12.7	28	28	31.3
	5	12.7	16	40	31.3
18	1	10.1	24	44	21.9
	2	19.6	16	40	24.4
	3	10.0	20	40	30.0
	4	15.6	20	40	24.4
	5	15.1	04	44	36.9
36	1	09.4	12	36	42.6
	2	16.3	12	40	31.7
	3	11.8	12	44	32.2
	4	17.8	04	48	30.2
	5	19.4	08	44	28.6

TABLE A-3

BULK DENSITY VALUES WITHIN 0-6 INCH AND 6-18 INCH PROFILE

Composite Sample Number	Depth in Inches	B.D. in gm/cc	Depth in Inches	B.D. in gm/cc
1	0-6	1.555	6-18	1.674
2	0-6	1.498	6-18	1.352
3	0-6	1.465	6-18	1.512
4	0-6	1.517	6-18	1.604
5	0-6	1.449	6-18	1.681

TABLE A-4

DETERMINATION OF MOISTURE CONTENT AT FIELD CAPACITY BY
THE POROUS PLATE METHOD

Depth in Inches	Composite Sample	Sample Wet Weight (gm.)	Sample Dry Weight (gm.)	Moisture by Weight (percent)	Moisture* by Volume (percent)
6	1	26.82	22.47	19.36	30.10
	2	25.75	21.87	17.74	26.57
	3	26.10	21.63	20.66	30.26
	4	30.80	25.80	19.38	29.39
	5	28.10	24.00	22.17	32.12
18	1	29.00	23.79	22.03	36.87
	2	28.75	24.21	18.75	29.10
	3	27.40	22.35	21.50	32.50
	4	24.50	19.50	25.64	41.12
	5	32.90	26.00	26.53	44.59
36	1	26.28	20.54	28.14	47.10
	2	25.28	19.90	27.03	41.95
	3	29.04	22.63	28.32	42.81
	4	31.84	24.88	27.97	44.75
	5	27.39	21.75	25.93	43.58

*Moisture content by volume is the product of moisture control by weight and bulk density.

TABLE A-5

DETERMINATION OF MOISTURE CONTENT AT WILTING POINT BY THE
PRESSURE MEMBRANE METHOD

Depth in Inches	Composite Sample	Sample Wet Wt. in gm.	Sample Dry Wt. in gm.	Percent M.C. by Weight Wilt. Point	Percent M.C.* by Volume Wilt. Point
6	1	26.80	23.88	12.30	19.13
	2	28.50	25.80	10.46	15.67
	3	24.00	21.51	11.57	16.95
	4	26.30	23.81	10.45	15.85
	5	26.20	23.00	13.90	20.14
18	1	26.90	23.80	13.10	21.93
	2	26.30	23.40	13.24	20.55
	3	28.85	25.50	13.13	19.85
	4	24.10	21.54	11.88	19.06
	5	23.60	20.88	13.02	21.89
36	1	25.70	22.75	13.05	21.85
	2	25.40	22.35	13.64	21.14
	3	23.00	20.02	14.88	22.46
	4	23.30	20.54	13.43	21.54
	5	26.50	23.86	11.06	18.58

*Moisture content by volume is the product of moisture control by weight and bulk density.

TABLE A-6

CORN YIELD (GREEN MATTER) AND AVERAGE SOIL MOISTURE
LEVEL WITHIN ELEVATION RANGES FOR MONTH OF JULY

Site	Yield (lbs/ac Green Matter)	Elevation Range	Moisture* (Inches- Water)
1	44286	52-54	5.17
2	34364	50-52	5.88
3	56507	50-52	5.44
4	40293	50-52	5.07
5	51062	50-52	5.60
6	39688	52-54	5.03
7	45012	52-54	5.04
8	37147	52-54	5.40
9	45980	50-52	6.06
10	50578	52-54	5.28
11	39930	52-54	5.63
12	58080	50-52	5.61
13	39325	52-54	5.25
14	53240	50-52	6.01
15	52635	48-50	7.23
16	52756	48-50	6.81
17	27225	48-50	8.77
18	52998	50-52	5.05
19	45012	50-52	5.38
20	46706	50-52	4.99
21	48642	50-52	5.06
22	48158	48-50	5.62
23	41140	48-50	5.05
24	52635	50-52	5.88
25	43076	50-52	5.90

*Moisture in the 24-inch soil profile.

TABLE A-7

INCHES WATER AT FIELD CAPACITY, WILTING POINT AND
FOUR BARS TENSION WITHIN THREE SOIL PROFILES

Depth in Inches	Composite Sample Number	Inches Water at Field Capacity (1/3 Bars ^a Tension)	Inches Water at Wilting Point (15 Bars ^b Tension)	Inches Water at Limiting Soil Moisture for Corn (4 Bars ^c Tension)
0-12	1	3.61	2.29	2.52
	2	3.18	1.88	2.15
	3	3.63	2.03	2.35
	4	3.52	1.90	2.24
	5	3.85	2.41	2.63
12-24	1	4.42	2.63	3.30
	2	3.49	2.46	2.63
	3	3.90	2.38	2.65
	4	4.93	2.28	3.29
	5	5.35	2.62	3.58
0-24	1	8.03	4.92	6.15
	2	6.68	4.34	5.14
	3	7.53	4.41	5.42
	4	8.46	4.18	5.25
	5	9.20	5.04	6.60

^a1/3 bars tension = 5 psi.

^b15 bars tension = 221 psi.

^c4 bars tension = 59 psi.

TABLE A-8

CALCULATION OF AVERAGE POTENTIAL EVAPOTRANSPIRATION RATE
BY THORNTHWAITE METHOD

Month	Annual Mean Temp. (°F)	Heat Index	Unadj. PE Inches	Corr. Factor	Adj. Inches
May	67.4	7.95	0.13	36.6	5
June	74.8	10.59	0.16	36.6	6
July	77.7	11.70	0.17	37.2	6
August	76.7	<u>11.31</u>	0.17	34.8	6
Total		31.55			
Daily Potential Evapotranspiration					
May	----- 0.16 in/day				
June	----- 0.20 in/day				
July	----- 0.19 in/day				
August	----- 0.19 in/day				

TABLE A-9

SOIL MOISTURE BALANCE PROCEDURE FOR CORN GROWING SEASON
(May 1-August 10, 1976)

Day	PE, Inches	P, Inches	SM, Inches
May			
1	0.16	0.50	2.27
2	0.16	0.00	2.11
3	0.16	0.00	1.95
4	0.16	0.00	1.79
5	0.16	0.00	1.63
6	0.16	0.50	1.97
7	0.16	0.07	1.88
8	0.16	0.00	1.72
9	0.16	0.00	1.56
10	0.16	0.00	1.40
11	0.16	0.27	1.51
12	0.16	0.00	1.35
13	0.16	0.03	1.22
14	0.16	0.56	1.62
15	0.16	1.63	2.27
16	0.16	0.09	2.34
17	0.16	0.00	2.18
18	0.16	0.16	2.02
19	0.16	0.00	1.86
20	0.16	0.00	1.70
21	0.16	0.00	1.54
22	0.16	0.00	1.38
23	0.16	0.03	1.25
24	0.16	0.00	1.09
25	0.16	0.00	0.93
26	0.16	0.00	0.77
27	0.16	0.03	0.64
28	0.16	0.98	1.46
29	0.16	0.59	2.27
30	0.16	0.00	2.11
31	0.16	0.00	1.95

TABLE A-9 (continued)

Day	PE, Inches	P, Inches	SM, Inches
<u>June</u>			
1	0.20	0.00	1.75
2	0.20	0.07	1.62
3	0.20	0.41	1.83
4	0.20	0.00	1.63
5	0.20	0.00	1.43
6	0.20	0.00	1.23
7	0.20	0.00	1.03
8	0.20	0.00	0.83
9	0.20	0.00	0.63
10	0.20	0.00	0.43
11	0.20	0.00	0.23
12	0.20	0.00	0.03
13	0.20	0.00	--*
14	0.20	0.00	--
15	0.20	0.00	--
16	0.20	0.01	--
17	0.20	0.00	--
18	0.20	0.07	--
19	0.20	1.67	1.47
20	0.20	0.47	1.74
21	0.20	0.00	1.54
22	0.20	0.00	1.34
23	0.20	0.00	1.14
24	0.20	0.00	0.94
25	0.20	0.04	0.78
26	0.20	0.15	0.73
27	0.20	0.00	0.53
28	0.20	0.08	0.41
29	0.20	0.33	0.54
30	0.20	0.16	0.50
<u>July</u>			
1	0.19	0.00	0.31
2	0.19	0.00	0.12
3	0.19	0.06	--
4	0.19	1.53	1.34
5	0.19	0.19	0.34

TABLE A-9 (continued)

Day	PE, Inches	P, Inches	SM, Inches
6	0.19	0.07	1.22
7	0.19	0.00	1.03
8	0.19	0.21	1.05
9	0.19	0.00	0.86
10	0.19	0.00	0.67
11	0.19	0.00	0.48
12	0.19	0.60	0.89
13	0.19	0.00	0.70
14	0.19	0.00	0.51
15	0.19	0.38	0.70
16	0.19	0.45	0.96
17	0.19	0.00	0.77
18	0.19	0.00	0.58
19	0.19	0.00	0.39
20	0.19	0.03	0.23
21	0.19	0.00	0.04
22	0.19	0.00	--
23	0.19	0.00	--
24	0.19	0.00	--
25	0.19	0.00	--
26	0.19	0.00	--
27	0.19	0.00	--
28	0.19	0.00	--
29	0.19	0.22	--
30	0.10	0.22	0.03
31	0.19	0.01	--
<u>August</u>			
1	0.19	0.00	--
2	0.19	0.00	--
3	0.19	0.80	0.61
4	0.10	0.00	0.42
5	0.19	0.00	0.23
6	0.19	0.40	0.04
7	0.19	0.06	0.25
8	0.19	0.00	0.06
9	0.19	0.00	--
10	0.19	0.00	--

*Soil moisture deficiency day.

APPENDIX B

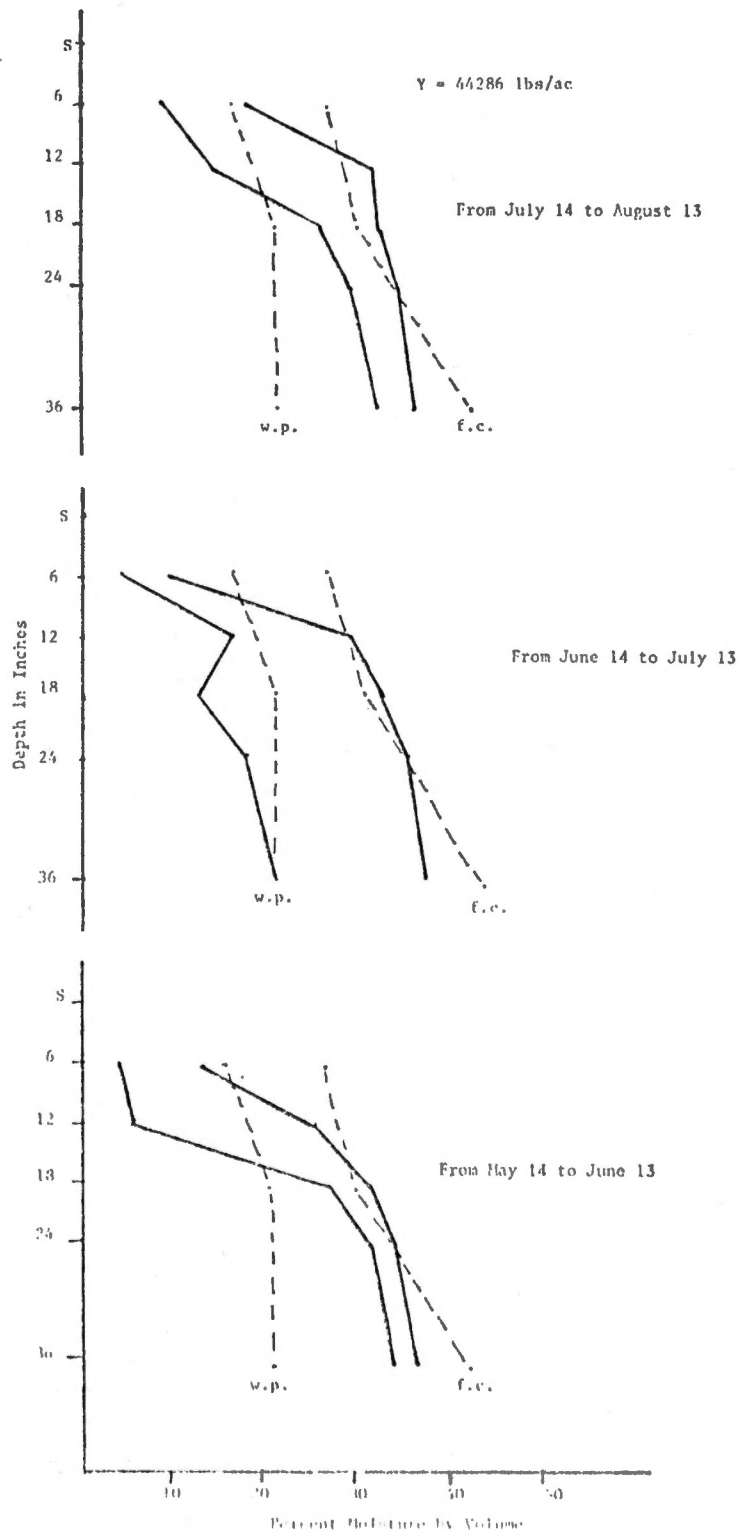


Figure B-1. Range of observed soil moisture at site 1.

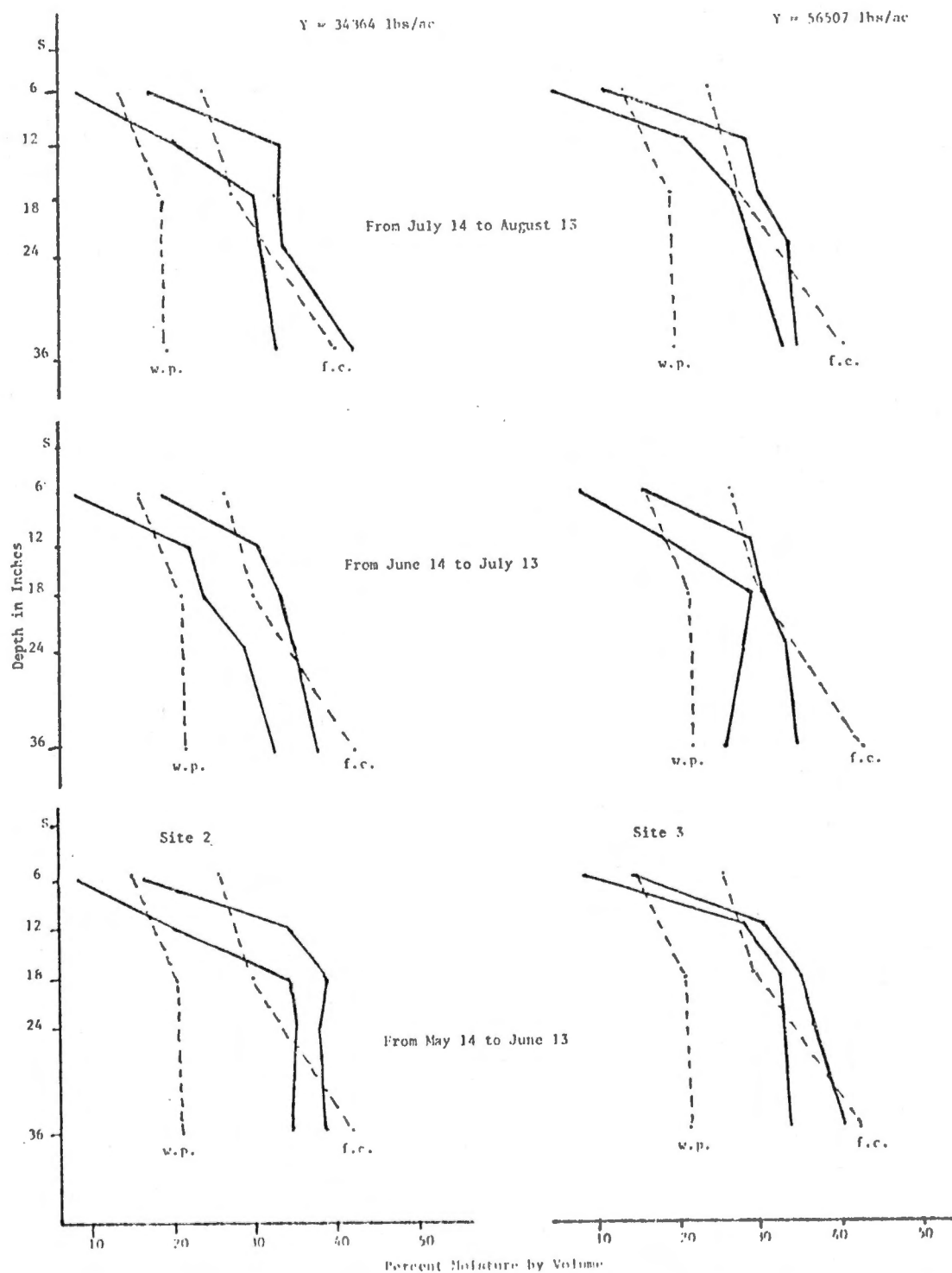


Figure B-2. Range of observed soil moisture at sites 2 and 3.

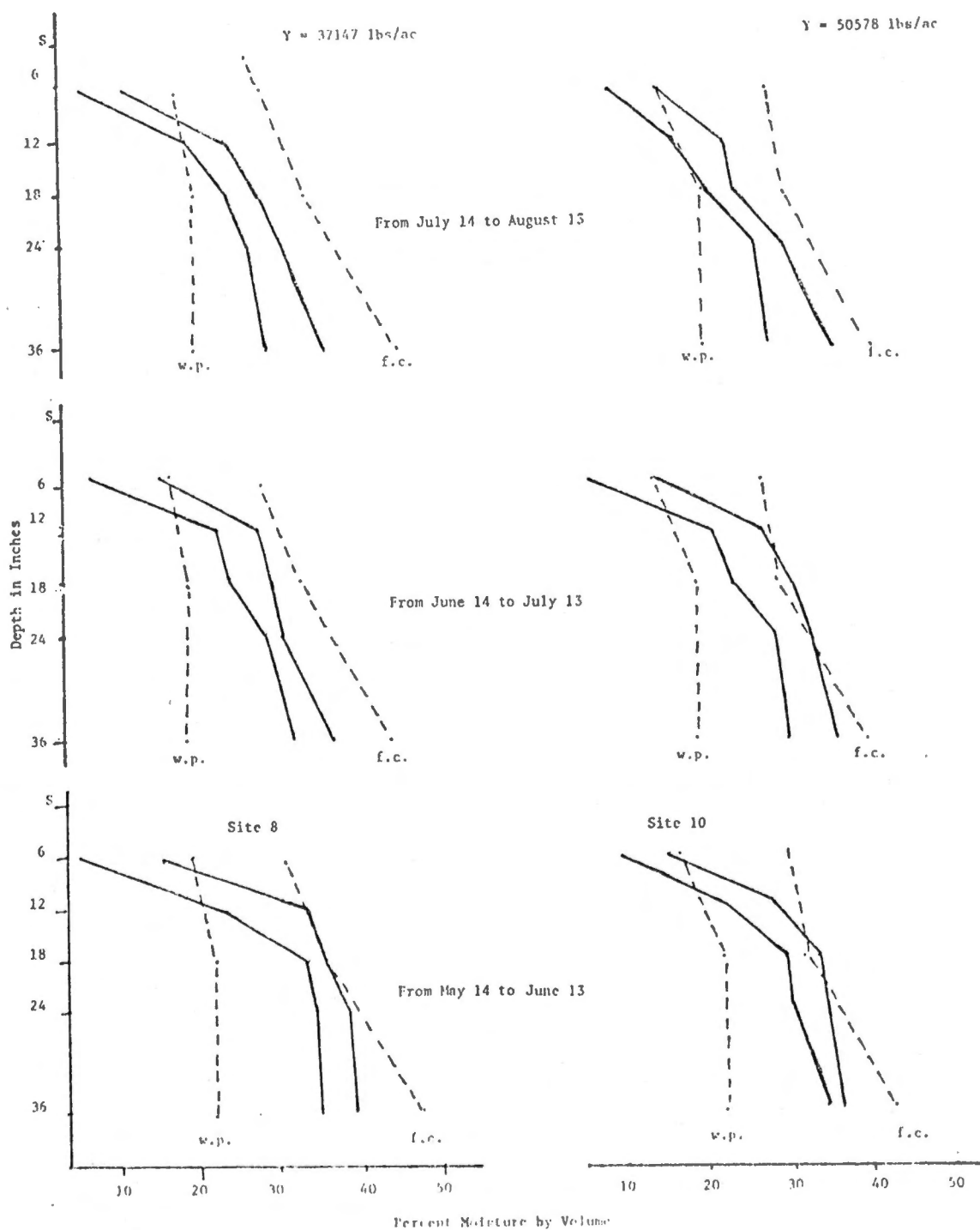


Figure B-3. Range of observed soil moisture at sites 8 and 10.

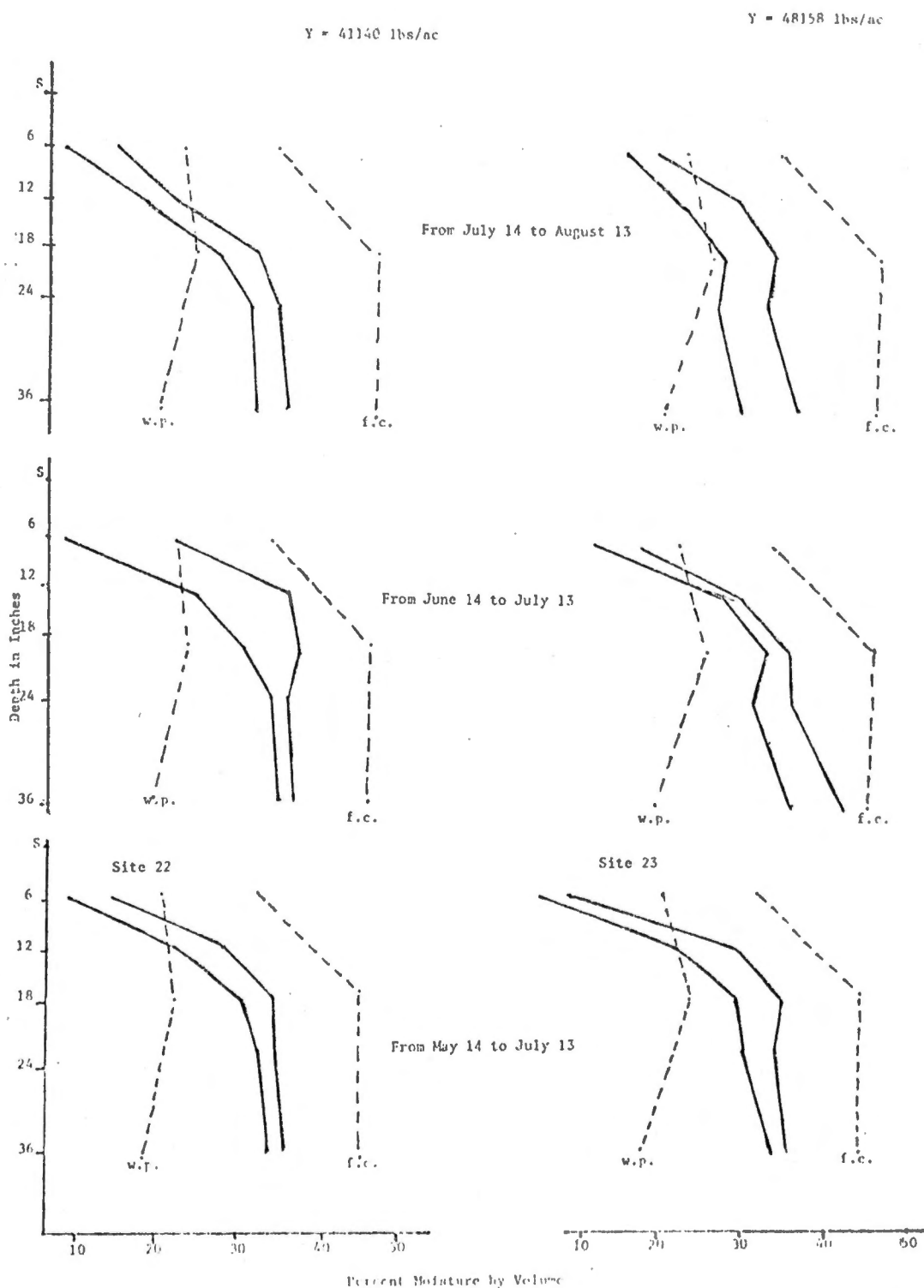


Figure B-4. Range of observed soil moisture at sites 22 and 23.

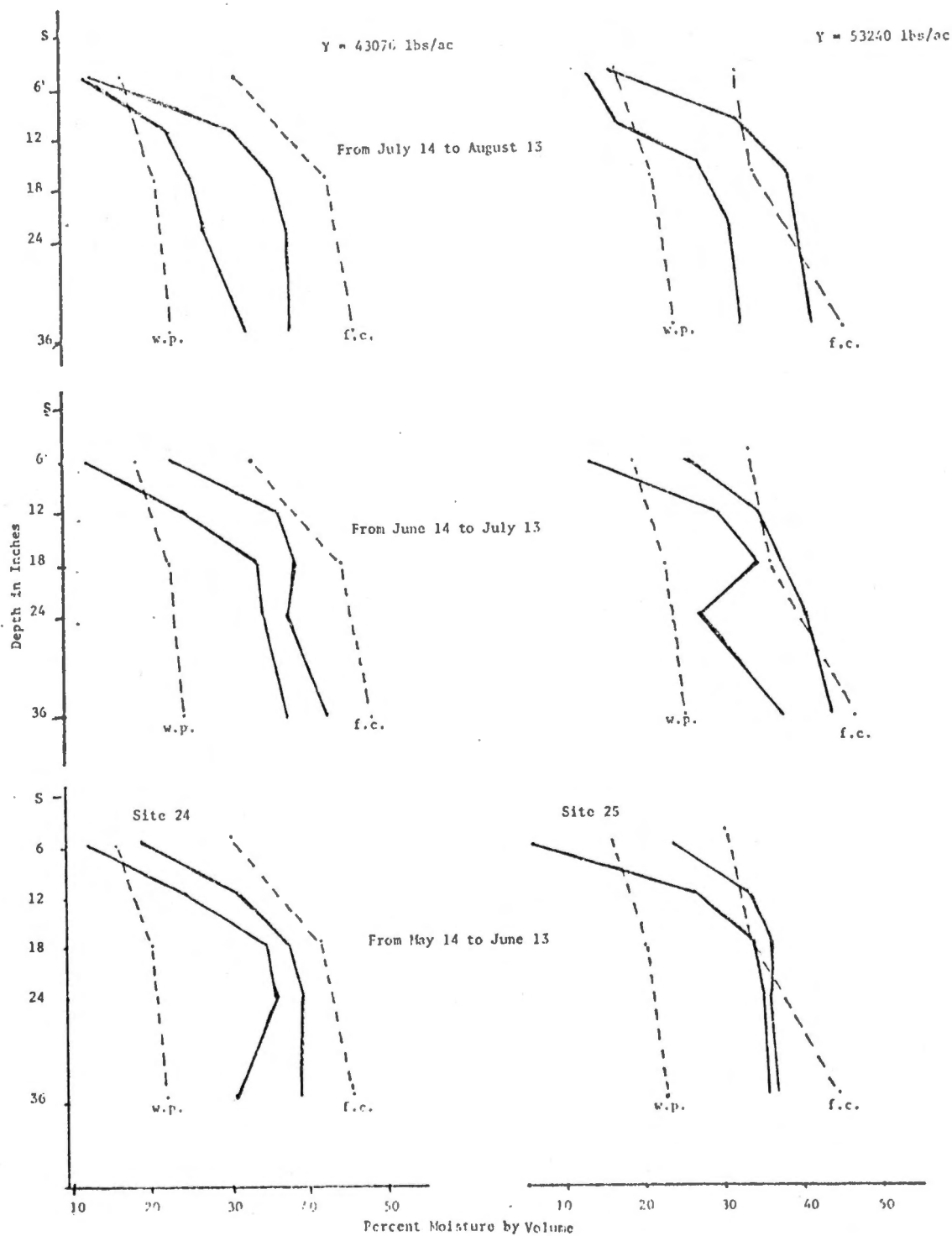


Figure B-5. Range of observed soil moisture at sites 24 and 25.

VITA

Naufal Al-Marsi was born on December 26, 1950, in Mosul, Iraq. He was graduated from high school in 1968 and from the College of Engineering at Mosul University with a B.S. degree in Agricultural Engineering in 1972. He then served for eighteen months in the Iraqi Army. In 1973 he was appointed to work as an assistant agricultural engineer at the University of Mosul. In 1974 he was granted a full scholarship from the Iraqi government to study agricultural engineering in the United States. He entered the University of Tennessee at the beginning of the summer quarter in 1975.

He was married to Huda Abdul Chani in September, 1976. He plans to pursue the Ph.D. degree in agricultural engineering before returning to Iraq where he intends to teach and conduct research.