May 27, 1964

To the Graduate Council:

I am submitting herewith a thesis written by Butler Eugene Holt entitled "Corn Yields and Evapotranspiration as Influenced by Moisture Level, Nitrogen Levels, and Several Climatic Factors." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agronomy.

W L Parlas
Major Professor

We have read this thesis and recommend its acceptance:

Frank L Bell

Luther H. Keller

Accepted for the Council:

Hilton A. Smith
Dean of the Graduate School

CORN YIELDS AND EVAPOTRANSPIRATION AS INFLUENCED BY MOISTURE LEVELS, NITROGEN LEVELS, AND SEVERAL CLIMATIC FACTORS

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

Butler Eugene Holt

June 1964

ACKNOWLEDGEMENTS

The author wishes to express his gratitude and appreciation to:

Dr. W. L. Parks, his major professor, for his advice, encouragement, and assistance throughout the course of this investigation,

Dr. F. F. Bell and Professor L. H. Keller for their valuable suggestions and cooperation while serving on the advisory committee,

Dr. H. A. Fribourg for supplying a part of the data and for valuable suggestions in the statistical part of the thesis,

Mr. J. R. Overton, Agronomist and Mr. J. W. Measells, Meteorologist at the Agricultural Experiment Station at Jackson, for supplying part of the data used in this thesis,

The experiment station superintendents and staff at both the Knoxville and Jackson stations who contributed their time and facilities,

The Tennessee Valley Authority and the University of Tennessee Agricultural Experiment Station for making this investigation possible,

Mr. J. V. Whipple and his staff at the University Computing Center for their cooperation and help in processing the data,

Mr. C. E. Freeman, Graduate Assistant in Agronomy, for help in making observations,

My wife for her assistance and many sacrifices during the past two years.

574873

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	LITERATURE REVIEW	2
	Early Work and Definitions	2
	Factors Affecting Consumptive Use	8
	Influence of Moisture Stress on ET	10
	Effect of Stress at Different Growth Stages	13
	Moisture Extraction Patterns	15
	Quantity of Water Used by Crops	19
	Effect of Nitrogen Levels and Plant Population Levels on Moisture Use	21
	Determining When and How Much to Irrigate	23
	Empirical Formulae for Estimating ET. from Meteorological Data	26
	Blaney and Criddle Method	26
	Hargreaves Method	27
	Lowery-Johnson Method	27
	Thornthwaite Formula	28
	Penman Method	28
	Atmometer Method	29
	Estimating ET. from Meteorological Data	30
III.	MATERIALS AND METHODS	38
	Neutron Moisture Meter	41

CHAPTER PAGE

III. (continued)

Equipment used. 41

Livingston Atmometer. 43

IV. RESULTS AND DISCUSSIONS 44

Correlations of Cumulated Water Loss From Open Pan with Cumulated ET. Under Various Treatments 45

Correlations of Cumulated Average ET. with Cumulated Water Loss From Atmometers. 55

Correlations of Cumulated Average ET. with Cumulated Temperatures and Relative Humidity. 55

Correlations of Cumulated Average ET. with Cumulated Sunshine Hours, Degree-Sunshine Hours, Wind Speed, and Total Solar Radiation at Knoxville. 59

Correlations of Cumulated Average ET. with Cumulated Sunshine Hours, Degree-Sunshine Hours, and Wind Speed at Jackson. 59

Correlations of Cumulated Water Loss from Open Pan with Cumulated Water Loss from Atmometers and Other Meteorological Factors. 62

Soil Moisture Depletion 65

Corn Yields as Influenced by Nitrogen Levels and Drouth Intensity. 73

V. SUMMARY AND CONCLUSIONS 78

LITERATURE CITED. 83

APPENDIX. 90

LIST OF TABLES

TABLE PAGE

I. Some Physical Characteristics of Sequatchie and Memphis Soils on Which Experiments were Conducted 42

II. Coefficients of Correlation, Values of r^2 and R^2, Standard Errors of Regression Coefficients, Standard Errors of Estimate, and Equations Describing the Relationships Between the Variables Under Study, in Corn on a Sequatchie Soil, at the Agricultural Experiment Station at Knoxville 46

III. Coefficients of Correlation, Values of r^2 and R^2, Standard Errors of Regression Coefficients, Standard Errors of Estimate, and Equations Describing the Relationship Between the Variables Under Study, in Corn on a Memphis Soil, at the Agricultural Experiment Station at Jackson 50

IV. Measured Evapotranspiration in Corn for Some Treatments on a Sequatchie Soil at Knoxville During 1962 91

V. Measured Evapotranspiration in Corn for Some Treatments on a Sequatchie Soil at Knoxville During 1963 92

VI. Measured Evapotranspiration in Corn for Some Treatments on a Memphis Soil at Jackson During 1962. 93

VII. Measured Evapotranspiration in Corn for Some Treatments on a Memphis Soil at Jackson During 1963. 94

TABLE PAGE

VIII. Measured Evapotranspiration in Corn Under Different Moisture and Nitrogen Levels on a Sequatchie Soil at Knoxville During 1962. 95

IX. Measured Evapotranspiration in Corn Under Different Moisture and Nitrogen Levels on a Sequatchie Soil at Knoxville During 1963. 96

X. Measured Evapotranspiration in Corn Under Different Moisture and Nitrogen Levels on a Memphis Soil at Jackson During 1962. 97

XI. Measured Evapotranspiration in Corn Under Different Moisture and Nitrogen Levels on a Memphis Soil at Jackson During 1963. 98

XII. Drouth-Day Occurrence Using Four Periods at a 3.00 Inch Moisture Base at Knoxville and Jackson During 1962 and 1963 99

XIII. Drouth-Day Occurrence Using Nine Periods at a 3.00 Inch Moisture Base at Knoxville and Jackson During 1962 and 1963 100

XIV. Temperatures and Relative Humidity Recorded at the Agricultural Experiment Station at Knoxville During 1962. 101

XV. Temperatures and Relative Humidity Recorded at the Agricultural Experiment Station at Knoxville During 1963 102

TABLE PAGE

XVI. Temperatures and Relative Humidity Recorded at the Agricultural Experiment Station at Jackson During 1962 103

XVII. Temperatures and Relative Humidity Recorded at the Agricultural Experiment Station at Jackson During 1963 104

XVIII. Air Movement, Rainfall, Open Pan Evaporation, and Water Loss from Atmometers at the Agricultural Experiment Station at Knoxville During 1962 105

XIX. Air Movement, Rainfall, Open Pan Evaporation, and Water Loss from Atmometers at the Agricultural Experiment Station at Knoxville During 1963 106

XX. Air Movement, Rainfall, Open Pan Evaporation, and Water Loss from Atmometers at the Agricultural Experiment Station at Jackson During 1962 107

XXI. Air Movement, Rainfall, Open Pan Evaporation, and Water Loss from Atmometers at the Agricultural Experiment Station at Jackson During 1963 108

XXII. Effect of Soil Moisture on the Yield Response of Corn to Applied Nitrogen Fertilizer at the Agricultural Experiment Station at Knoxville During 1962 and 1963. . . 109

XXIII. Effect of Soil Moisture on the Yield Response of Corn to Applied Nitrogen Fertilizer at the Agricultural Experiment Station at Jackson During 1962 and 1963. . . . 110

LIST OF FIGURES

FIGURE PAGE

1. Relationship Between Average ET. in Corn and Water Loss From Open Pan at Knoxville and Jackson. 54

2. Relationship Between Water Loss from "B-W" and ET. in Corn at Knoxville and Jackson. 56

3. Relationship Between Maximum, Mean and Dew Point Temperatures and ET. in Corn at Knoxville 57

4. Relationship Between Maximum, Mean and Dew Point Temperatures and ET. in Corn at Jackson 58

5. Relationship Between Sunshine Hours, Wind Speed and ET. in Corn at Knoxville. 60

6. Relationship Between Sunshine Hours, Wind Speed and ET. in Corn at Jackson. 61

7. Relationship Between Water Loss from "B-W" and from Open Pan at Knoxville and Jackson 63

8. Relationship Between Mean Temperature and Water Loss from Open Pan at Knoxville and Jackson. 64

9. Net Soil Moisture Depletion in 1962 for Corn on a Sequatchie Soil When Unirrigated and Receiving 120 lb. N/A 66

10. Net Soil Moisture Depletion in 1963 for Corn on a Sequatchie Soil When Unirrigated and Receiving 120 lb. N/A 67

FIGURE PAGE

11. Net Soil Moisture Depletion in 1962 for Corn on a Memphis Soil When Unirrigated and Receiving 120 lb. N/A 68

12. Net Soil Moisture Depletion in 1962 for Corn on a Memphis Soil When Irrigated at 2 Atmospheres Tension and Receiving 120 lb. N/A 69

13. Net Soil Moisture Depletion in 1962 for Corn on a Memphis Soil When Irrigated at 2 Atmospheres Tension and Receiving No Nitrogen 70

14. Net Soil Moisture Depletion in 1962 for Corn on a Memphis Soil When Irrigated at 2 Atmospheres Tension and Receiving 300 lb. N/A 71

CHAPTER I

INTRODUCTION

Irrigation is most effective when used at the right time and in proper amounts. To make irrigation more efficient, means are being sought for predicting the proper time to irrigate and determining the amount of water required by each crop.

This study was conducted to ascertain the effect of nitrogen levels and moisture levels on the yield and moisture use by corn and the effect of climatic factors such as temperature, solar radiation, wind, sunshine, and humidity on evapotranspiration and evaporation from open pan and atmometers. The untimate aim is to relate corn yield to certain climatic factors and to explore the possibility of guiding the farmers in scheduling their irrigation practices based on climatic data.

CHAPTER II

LITERATURE REVIEW

I. EARLY WORK AND DEFINITIONS

Irrigation studies have been conducted in two phases (27). The first was aimed at determining the levels of soil moisture needed to maintain satisfactory growth of various crops. The second part of the task has been the development of a suitable means for determining when the soil moisture has been reduced to the point where irrigation should be applied. This is the phase of the problem with which we will be concerned in this report.

Transpiration of water by plants has been studied for the past two centuries, and evaporation of water has also been studied over a long period. However, it was not until the first part of this century that the terms "consumptive use" and "evapotranspiration" came into general use. And it has been only since 1935 that sufficient data have been available on this subject so that designers of irrigation and drainage systems and hydrologists have had confidence in the use of such material (4).

Consumptive use or evapotranspiration (ET.) is the unit amount of water used on a given area in transpiration, building of plant tissue, and evaporation from adjacent soil, snow, or intercepted precipitation in any specified time. It is expressed in volume per unit area, such as inches per acre, or in depth, such as inches (4).

It is the best index of irrigation requirements, according to Blaney (2, 3). Consumptive irrigation requirement is the depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water that is required consumptively for crop production (4).

As early as 1911, Briggs and Shantz (7) worked on water requirements of plants. They measured the water requirement of 44 species and varieties in 1912 and 55 in 1913. They defined water requirement as "the ratio of the weight of water absorbed by a plant during its growth to the weight of dry matter produced, exclusive of roots." They found that varieties of the same crop differ widely in their water requirement, as much as 31 per cent difference in the corn varieties with the highest and lowest water requirement.

Although the term "water requirement" is a useful term in determining the efficiency with which plants use water, from a practical aspect the terms "consumptive use" or "irrigation requirement" may have more meaning.

The irrigation requirement is the amount of water, exclusive of precipitation, that is needed for the production of crops. It includes plant transpiration, evaporation, deep percolation, and other economically unavoidable wastes (2, 3).

Sampling fields at frequent intervals and ascertaining the moisture content by gravimetric methods provides the most accurate measure of soil moisture. Sampling, however, is time consuming and requires considerable skill and equipment (27).

Halkias et al. (19) also indicated that the best measure of water

use by crops is by soil sampling to obtain change in soil moisture. Certain conditions must be satisfied for this method to be successful, however. The crop being studied must have a good, vigorous root system which thoroughly permeates the soil. The soil must be deep enough to accommodate the full rooting depth of the crop, but not so dense that it inhibits penetration of roots. The soil should be fairly uniform with no sharp changes in texture or structure. The water table must be below the reach of roots.

Several instruments are available which give reliable measurement of soil moisture levels, but their use requires a financial outlay as well as considerable time and skill and they may not be practicable for the farmer. Some of these instruments presently in use are tensiometers, electrical resistance blocks, and neutron scattering devices.

Empirical formulae using average temperature, hours of sunlight, and wind movement have also been employed to estimate the amount of water lost from the soil. This approach has the advantage of being simple and easy to use. Calculations can be made whenever desired without having to go to the field to make measurements. Obviously, however, the accuracy of this approach is not as great as may be desired (27).

A knowledge of the moisture content of the soil is indispensable in irrigation experiments according to Van Bavel (62). Measurement of soil moisture content has received much attention in the past and, at the present time, new emphasis upon this problem is evident. In

spite of all the work that has been done, no single satisfactory method has been produced. A satisfactory method is one whereby moisture content can be found rapidly, accurately, and repeatedly on the same location without undue expense of time and money.

The stress with which soil moisture is held determines its availability to plants. In characterizing soil moisture availability, the average stress must be used, recognizing at the same time that widely different stress values exist simultaneously in the root zone. It would seem advantageous, therefore, to employ a method in which the root zone is examined as a whole, such as the evapotranspiration (ET.) method.

Thornthwaite (59) originated the concept of potential evapotranspiration (P.E.) in 1944 and defines it as "the amount of water which will be lost from a surface completely covered with vegetation if there is sufficient water in the soil at all times for the use of the vegetation." He further points out that the vegetation of deserts is sparse and uses little water because water is deficient. If more water were available, the vegetation would be less sparse and would use more water. There is a distinction, then, between the amount of water that actually evaporates and transpires (ET.) and that which would transpire and evaporate if it were available. When the water supply increases, as in a desert irrigation project, ET. rises to a miximum that depends only on climate. This we call potential evapotranspiration (P.E.) as distinct from actual evapotranspiration (ET.)

Explaining further, Van Bavel (62) says that the ET. method

embodies several laws and experiences from the fields of plant physiology, soil science, and meteorology, but the two most important principles are these: (1) when soil moisture is plentiful, ET. depends primarily upon weather conditions, (2) the moisture content of the root zone at a given time equals that at a previous time, plus the difference between income and outgo of water over the elapsed period.

It is possible, therefore, by applying these principles to find the moisture content of the root zone through a measure or an estimate of gains and losses of water.

In using the ET. method we are concerned with the total amount of plant-available water rather than the moisture content of the soil per se. The total amount of plant-available water in the soil at any given time is determined by the following three factors: (1) the soil moisture content by volume, (2) the depth to which roots extend, and (3) the soil moisture content by volume at which water is no longer available to plants (61). Properties (1) and (3) usually depend upon depth. Further, item (2) depends upon the nature of the crop and the soil, and also, in some cases, upon the stage of development of the crop. When there is appreciable dependence upon depth of items (1) and (3), the usual procedure is to evaluate them horizon by horizon, and to average the values, weighing each with the thickness of the horizon. Item (1) above is then represented by field capacity moisture content on a volume basis. It is best determined by a sampling of the profile after a heavy rain or irrigation for moisture content by weight and for bulk density (61). Item (2) above already has been mentioned. Usually,

the thickness of the root zone is found by inspection. Careful study of changes in moisture content of the soil profile during prolonged dry periods is probably the most desirable method to find the extent of the root zone. Often, this method will require much time and effort (61). The limit of water availability, item (3) above, is ordinarily gauged from a knowledge of the so-called wilting percentage. In reality, there is a wilting range which seems to depend upon soil and plant factors (61).

The wilting percentage is determined with pressure cells. Since this figure is expressed on a dry weight basis, it is necessary to know bulk density in order to find the corresponding moisture content by volume. Information on wilting percentage can also be obtained by periodic sampling of the profile during prolonged dry periods.

The figure for maximum amount of plant-available water may be obtained by multiplying the difference between field capacity and wilting percentage, both expressed on a volume basis with the depth of the root zone in inches, thus arriving at the result expressed in inches of precipitation equivalent.

Daily measurement of rain at the site of interest is indispensable in the ET. method because in maintaining the soil moisture balance, it is essential to know the amount of available moisture in the rooting zone of the crop, the moisture additions due to rains or irrigation, and the ET. for the growth periods of the crop (62).

Estimating ET. is, understandably, the other critical aspect of the ET. method. It would never be possible to make adequate estimates

of the amount of ET. if it were not for the fact that one is dealing with a conservative process. That is, first of all, on any day its intensity is bounded by definite limits. These limits are zero and a maximum value which depends upon latitude and time of the year. Secondly, ET. is principally dependent upon incident radiant energy. The value of the latter is determined in the first instance by factors that are astronomical and geographical and, therefore, precisely predictable. Cloudiness also controls incident energy, and it tends to vary from day to day in an unpredictable fashion. It is not too difficult to measure cloudiness or sunshine duration.

Another factor which is significant for ET. is air temperature. This is principally explained by the fact that warm air can contain more water in vapor form than cold air.

The climatic elements such as temperature, solar radiation, humidity, air movement, precipitation, and evaporation may be measured at some representative weather stations in the locality. If the ET. could be predicted by making use of these records, it would be of great use to the farmers in scheduling irrigation practices.

II. FACTORS AFFECTING CONSUMPTIVE USE

Many factors influence the amount of water consumed by plants. Among them are climate, length of growing season, stage of growth and total growth of the plants, irrigation practices and water supply, stand, fertility of the soil, and topography. Physical properties of the soil, which control water movement, have an influence also. Disease and

insect pests affect growth and therefore the use of water by plants.

The climatic factors believed to have the greatest effect on consumptive use on which data are generally available are temperature, precipitation, humidity, wind movement and growing season (2, 3, 4, 41, 48, 60).

The rate of water use by crops in any particular locality is probably affected more by temperature than by any other factor. Abnormally low temperatures may retard plant growth and unusually high temperatures may produce dormancy (2, 5). In the intermediate temperature range, however, the rate of both evaporation and transpiration are increased by a rise in temperature.

Evaporation and transpiration are accelerated by days of low humidity and slowed during periods of high humidity. Likewise, evaporation of water from land and plant surfaces takes place much more rapidly when there is moving air than under calm conditions.

The growing season, which is tied rather closely to temperature, has a major effect on seasonal irrigation water needs of plants. Although growing season may be used as a guide for computing consumptive use and irrigation requirement, actual data on dates of planting and harvesting of crops and average annual dates of first and last irrigations are important in determining consumptive irrigation requirements of crops.

Latitude may hardly be called a climatic factor, but it does have considerable influence on rate of consumptive use of water by various plants. The hours of daylight during the summer are much

greater in northern latitudes than at the equator. The longer day may allow plant transpiration to continue for a longer period each day and to produce an effect similar to that of lengthening the growing season (2).

The amount of water transpired is least when the corn plant is small, increases to a maximum at about silking time, and continues at a fairly high rate until near maturity (48). Any factors that promote growth will also increase consumptive use of water by corn (25).

Evaporation of water from the soil surface and the water use by corn are intensified by frequently wetting the soil, because moisture in the surface evaporates more rapidly than moisture at greater depths (48).

In an experiment conducted by Robins and Domingo (49) water use by corn was influenced markedly by the moisture treatments. When a severe deficit occurred during the fertilization period, water use was lowered by reduction in size of plants as well as by reduction in transpiration during the deficit period. Removal of the available water prior to maturity reduced water use whereas a similar removal following maturity had little effect.

III. INFLUENCE OF MOISTURE STRESS ON ET.

Early research upon plant-soil moisture relationships was based principally upon moisture content effects. It was soon recognized, however, that plants performed equally well in soils with very diverse moisture contents. With the advent of the energy concept of soil

moisture and suitable devices for measuring energy levels, came the recognition that static energy levels were a dominant influence in moisture utilization. A considerable amount of diverse opinion evolved concerning moisture availability and magnitude of ET. within the energy range from field capacity to permanent wilting percentage (45).

Veihmeyer and Hendrickson (64, 65) reported that water could be used with equal facility by plants in the moisture range from field capacity to permanent wilting percentage. This held true whether the rate was high or low, but changed markedly at the permanent wilting percentage.

Taylor (56), on the other hand, said if this was so, the facility with which plants can get water must increase as the energy requirement to remove water increases. He and Haddock (57) discount this, however, on the basis that the work required to remove a given volume of water from the soil results from overcoming the tension in the soil water and transporting the water vertically in the gravitational field of the earth. As tension increases, the amount of water that can be supplied to a uniform absorber in the soil in a given time is decreased and the "water supplying power" as defined by Livingston (34) is lessened.

Plant growth is primarily the result of two major processes: cell division and cell enlargement. Wadleigh (66) reported that soil moisture deficits affected growth mainly by inhibiting cell enlargement, rather than by affecting cell division. Tugor pressure within the plant is reduced as moisture stress is increased. Tugor pressure is the force that brings about cell enlargement, and its effectiveness is controlled

by the action of auxin within the cell. Thus, moisture stress may reduce growth through the reduction in tugor pressure within the plant.

Wadleigh (66) found that as the soil dried out toward the permanent wilting percentage, there was but little increase in moisture tension even when two-thirds of the available moisture had been used. On the other hand, as permanent wilting percentage was approached, there was an enormous increase in moisture tension associated with a small decrease in moisture content. In general, he says, when two-thirds to three-fourths of the available water has been exhausted from the moisture reservoir, plants may stop growing.

In an experiment by Hagan et al. (18) dry weight production of vegetative material, photosynthesis and respiration rates were not affected appreciably until the moisture content in the entire root zone approached the permanent wilting percentage. Green weight production and shoot elongation were reduced significantly when the soil moisture content fell into the lower half of the available range. Chemical composition, flower formation, and seed production were also influenced by moisture conditions within the available range.

Increases in soil moisture tension from one to twelve atmospheres brought about progressively smaller increases in radicle elongation, fresh weight, dry weight, and degree of seedling hydration in an experiment conducted by Gingrich and Russell (17). Growth properties were most sensitive in the range between one and three atmospheres.

Experiments conducted by Peters (45) on prepared mixtures of a sand and clay soil indicate that the uptake of water by corn roots is

a function of the specific moisture content as well as the moisture tension. His data show that uptake of water and elongation of corn roots are decreased as the moisture tension increases and that uptake of water and root elongation decreases as the moisture content per unit tension decreases.

Haynes (22) found that quantity of vegetative growth was markedly affected by the degree of availability of soil moisture within the range from near saturation to near permanent wilting percentage. Availability of soil moisture did not affect the amount of water transpired per unit of plant dry weight produced within this soil moisture range. He concluded that plants which undergo daily recurrent temporary wilting, as a consequence of limited rate of water supply to roots, transpire smaller quantities of water per unit of dry weight than do plants which do not undergo temporary wilting.

In an experiment at Utah, Taylor (55) showed that over the entire plant growth range of soil moisture, the yield was reduced as mean tension increased. He concluded that this makes untenable the hypothesis that moisture is equally available to plants for growth throughout the entire plant growth range from field capacity to permanent wilting percentage.

IV. EFFECT OF STRESS AT DIFFERENT GROWTH STAGES

Robins and Domingo (49) concluded that soil moisture depletion to the wilting percentage by field corn at certain physiologic growth stages markedly depressed grain yields. Such depletions for periods

of one to two days during the tasseling or pollination period resulted in as much as a 22 per cent yield reduction and periods of six to eight days gave a yield reduction of about 50 per cent. Yield reduction due to the absence of available water after the fertilization period appeared to be related to the maturity of the grain when the available water was removed.

Denmead and Shaw (12) obtained very similar results. They found that moisture stress prior to silking reduced grain yield by 25 per cent, moisture stress at silking reduced grain yield by 50 per cent, and moisture stress after silking reduced grain yield by 21 per cent.

Miller and Duley (38) considered the growing period for corn to be 90 days, which was divided into three 30-day periods. The moisture supply during the second period had a much greater effect upon the total production of dry matter than the moisture content at any other time. Corn plants almost completely recovered from effects of drought at the beginning of the season and produced good yields, provided moisture was at an optimum after the first month. The production of grain depended more than any other part of the plant upon a plentiful supply of moisture during the last 30-day period of growth.

Taylor and Slater (58) found that field corn required water at low tensions from seeding to hard-dough stage for maximum growth and yield. It was particularly sensitive to moisture stress at silking time and shortly thereafter.

Howe and Rhoades (24) found that moisture supply at different periods greatly influenced the growth characteristics of corn. A

deficiency of moisture in the soil during early growth slowed down vegetative growth, delayed silking and tasseling and delayed maturity.

Best results with irrigation were obtained for most crops if water was applied before the average tension in the zone of rapid moisture removal went above four atmospheres and if irrigation was withheld whenever tension was below one-half to one atmosphere. A commonly accepted generalization calls for irrigating when 60 per cent of the available water in the root zone is depleted (58).

The optimum soil moisture range for corn appears to be at low moisture stress. Jamison and Beale (25) found the optimum range to be from 100 per cent of the available water stored in the soil down to about 50 per cent. Kiesselbach and Montgomery (28) suggested that the optimum soil moisture range was from 60 to 80 per cent saturation and that the amount of water used per gram of dry weight produced is least at 45 to 60 per cent saturation.

Yield increases per inch of water applied were greater for irrigations during tasseling to early dent stage than for irrigations throughout the growing season, according to Jamison and Beale (25).

V. MOISTURE EXTRACTION PATTERNS

Moisture removal rates have been used for many years to estimate root distribution in the soil, according to Vazquez and Taylor (63). Repeated observations have indicated that in the field, water is removed more rapidly from shallow depths when the soil is

uniformly moist throughout the profile, but that as the surface soil dries out, the largest amount of water is removed each day from successively lower depths. After an irrigation, water is again removed more rapidly from the surface and a similar cycle is repeated. It does not seem probable that root distribution would change in this manner.

Bennett and Doss (1) found that effective rooting depth decreased as soil moisture levels increased. A high percentage of the roots was found in the surface 12 inches of soil for all species regardless of soil moisture level. Soil moisture extraction was used with reasonable accuracy to estimate effective rooting depth.

Rhoades and Nelson (48) state that the depth of water removal by corn is very important to the irrigator. Corn roots first obtain water at a shallow depth immediately beneath the plant. Moisture removal then extends laterally until most of the available moisture in the plow layer is removed. After that, water is depleted from successively lower depths. The depth of moisture removal, however, is influenced by characteristics of the subsoil. In permeable soils, corn may remove moisture to a depth of five to six feet, according to irrigation practices. With subsoil of low permeability, root penetration and moisture removal may be limited to the upper two feet of soil. Irrigation or rainfall, on the other hand, greatly influence the pattern of water removal. Rooting is

shallower when plenty of moisture is available, and less water is obtained from lower depths.

Holt and Van Doren (23) found that corn used water to the five-foot level at kernel formation. The period of highest water requirement appeared to be from tasseling to kernel formation. Water requirement decreased sharply after this period. The greater usage of water by corn during the tasseling to kernel formation period is probably the reason for grain yields being reduced significantly if soil moisture is limited during this period.

They further observed that the pattern of water removal by corn in 1958 showed little soil moisture usage up to the time the plant was one foot high and after kernel formation. Water removal was confined to the upper two feet of soil for the period up to tasseling. After tasseling, however, the removal extended down to the third, fourth and even fifth foot.

In 1959, with comparable initial moisture and heavier early use than in 1958, the corn was extracting water from the fourth and fifth foot by tasseling time. They concluded that available soil moisture and rate of water usage determine the depth to which plants extract water.

For much of the Corn Belt the water required to produce high yields of corn exceeds by 50 per cent or more the normal rainfall for the months of June, July and August. High levels of production, therefore, are dependent to a considerable extent on the utilization

of water stored in the soil profile. Summer rainfall and irrigation appreciably affected the seasonal depth pattern of soil moisture change only in the top two feet of soil in their experiment.

Letey and Peters (33), too, found that corn yields were closely related to the reserve soil moisture conditions at the beginning of the growing season as well as to the soil moisture stress to which the plant is subjected during the growing season. The moisture stress effect upon growth was found to be closely related to seasonal weather and the efficiency of water use was strongly conditioned by soil temperature.

In explaining why water is extracted at successively greater depths as the soil dries out, Taylor and Haddock (57) state that a deficit of water in plant root tissues sets up forces across plant surface membranes causing movement of water into the plant. As the removal increases, the forces get stronger; this normally causes water to move into the plant more rapidly. The work per unit time that must be expended to remove a unit volume of water from the soil is here defined as the "water extracting power".

When moisture tension is uniform, the rate of removal of water at any depth is proportional to the root activity at that depth. The amount of water extracted from any depth interval if root activity is uniform is inversely related to the power required to remove water in that interval. For a time after an efficient irrigation, water will be held at low tensions and the rate of water uptake

will be more or less proportional to the activity of the roots.

As the tension in the soil moisture increases, the power required to remove any given volume of water per unit time will also increase. The total work expended must be increased if a larger volume of water is removed in a given time, but the power does not necessarily increase. When soil moisture tension is uniform throughout the profile, the water extracting power increases with the distance through which the water is moved against the force of gravity and the average distance through which water must travel to get to the plant root.

VI. QUANTITY OF WATER USED BY CROPS

Irrigated corn ordinarily uses 16 to 25 inches of water during the growing season, although up to 33 inches and as low as 12 inches have been reported (48). Six irrigations at Mitchel, Nebraska (24), that maintained a high level of soil moisture through the growing season gave a yield of 153 bushels per acre from 21.4 inches of water, or 7.1 bushels per acre-inch of water. On the plots where a high level of soil moisture was maintained only during the stage of growth just before tasseling through silking with three irrigations, the yield was 144 bushels per acre from 15.6 inches of water, or 9.2 bushels per acre-inch of water.

Tennessee data indicate that the maximum moisture use by corn is reached shortly before tasseling and remains fairly high through

kernel formation (41). About seven to ten bushels of corn can be produced per acre-inch of water if all other production factors are at an optimum level.

Corn grown on a plastic-covered monolith lysimeter at Coshocton, Ohio (21) showed that a very good crop was produced using only the water stored in the soil during the winter. A yield of 125 bushels per acre was obtained by using only 8.5 inches of water from the soil. From June 6 to September 9 when the cover was in place, estimated evaporation and measured transpiration amounts were an approximate 45:55 ratio. For the entire growing season, May 1 to September 9, it was estimated that the ET. would be composed of 56 per cent evaporation and 44 per cent transpiration. In their experiment, water-use efficiency was greatly increased because evaporation was eliminated by the use of the plastic cover.

In a similar experiment Peters and Russell (46), experimentally accomplished the separation of transpiration by corn and evaporation from the soil. It was found that as much as 50 per cent of total ET. could be accounted for by evaporation from the soil surface. It was further found that high yields of corn could be obtained with as little as 5.1 inches of water using this method.

Holt and Van Doren (23) also found that 40 to 50 per cent of the water losses during the growing season could be accounted for by evaporation.

Doss et al. (13) found that the average rates of moisture use by irrigated corn were from 0.07 to 0.23 inches per day with a range

from 0.05 inches at grain maturity to 0.30 inches per day from first tassel to late dough stage. Moisture was first extracted at a shallow depth beneath the plant, and then at successively lower depths. The depth of extraction increased with plant development.

VII. EFFECT OF NITROGEN LEVELS AND PLANT POPULATION LEVELS ON MOISTURE USE

It is generally accepted in the field of plant nutrition that the relative response obtained from a given increment of nitrogen is related to the supply of available moisture (40). Therefore, it would appear that the relative corn yield response to a given increment of nitrogen could be evaluated in terms of available moisture and so account for a large proportion of the among-year variance.

Nitrogen is the most limiting factor in corn production in North Carolina according to Krantz and Chandler (30). Corn yields increased about one bushel for each two pounds of nitrogen applied within the general range of response to nitrogen if sufficient moisture was available. They found the lowest cost of production per bushel came from the 120 pound rate of nitrogen, and the greatest profit per acre from the 160 pound rate. Other experiments have substantiated these findings (48).

The function of nitrogen in stimulating meristematic activities is clearly brought out from observations by Crowther (10) on number of flowers, number of nodes on the main stem and on the relative leaf growth rates.

Moisture was used at increasingly greater depths as the season

progressed in an experiment conducted by Koehler et al. (29). Total soil moisture use was increased by the addition of nitrogen fertilizer. The greatest amount of this increase resulted from the first increment of fertilizer added.

Weaver and Pearson (67) reported that ET. rate was affected very little by nitrogen level, but was influenced appreciably by plant population level.

Carlson et al. (8) also found that fertilizer use had little effect on ET. from corn, provided the soil was completely covered with vegetation. Neither nitrogen fertilization nor plant density influenced yields in non-irrigated treatments, but in irrigated treatments corn yields in both plant populations increased when nitrogen fertilizer was applied. Neither nitrogen fertilizers nor plant density appreciably affected ET. rate, although ET. was considerably greater for irrigated plots than for non-irrigated plots.

The pounds of dry matter produced per inch of water used in ET. (water-use efficiency) was appreciably increased by using a high plant population and nitrogen fertilizer. This effect was less marked in non-irrigated treatments. The amount of dry matter produced per inch of water used was greater on non-irrigated treatments than on irrigated treatments, except at high nitrogen rates in high plant densities. They concluded that if maximum efficiency of moisture use is to be realized, adequate fertilizer and plant densities are required.

Although crops grown on fertile soils may make a more efficient

use of water, the total amount of water used, because of increased crop production, may be greater than on less fertile soil and thus are often the first to lack water and wilt if the water supply is limited (20).

The effect of water on corn yields was influenced by levels of both nitrogen and seed in an experiment conducted by Smith and Thomas (51). In general, the greater the nitrogen level and/or seeding rate the greater the additional response to water.

VIII. DETERMINING WHEN AND HOW MUCH TO IRRIGATE

A common practice among farmers is to watch the plants for signs of moisture deficiency as a basis for supplying water. This is not satisfactory, because by the time the plant begins to show signs of water need they are already suffering and yield may have been reduced correspondingly.

Instead of watching the crop for indications of drouth, some investigators suggest watching the soil. It should be kept in mind that drouth does not begin when rain ceases but rather only when plant roots can no longer obtain moisture in needed amounts (60). Van Bavel (61) defines agricultural drouth as "a condition in which there is insufficient soil-moisture available to a crop" and drouth-day as "a period of one day during which the drouth condition exists."

In humid climates, if other factors are favorable, deficiencies of soil moisture may limit crop growth more often than is generally

realized, according to Richards and Richards (47). Studies of ET. in relation to climate indicate that yield-depressing drouths occur with almost statistical regularity in many climates, even though the average precipitation during the cropping season may exceed the total amount needed by crops.

Not only is it desirable to know the amount of water that it takes to produce a bushel of corn, a bale of cotton, etc., it is also essential to know the day to day and week by week moisture use rate by plants (41). It has been shown that many farm crops differ in their total moisture use. Likewise, the average daily soil moisture use by a specific crop may vary considerably due to the moisture regime experienced as the crop develops.

Blaney and Criddle state that the available water supply for an area influences the type of crops grown and their irrigation requirements (2, 3). In some places the quality of the water also affects irrigation requirements, and as much as 20 per cent more irrigation water is needed to control the accumulation of salts in the soil.

The net amount of irrigation water necessary to satisfy consumptive use during any period is found by subtracting the effective precipitation and other available water from the total consumptive use requirement for the period (4, 5). The net requirement of irrigation water, divided by irrigation efficiency indicates the overall irrigation requirement of the crop.

The irrigation efficiency is the percentage of irrigation water that is available for consumptive use by crops. Generally, not more

than 60 per cent of the water delivered to the field is made available for consumptive use of crops (2, 3). The irrigation efficiency may be determined from field studies or estimated by making allowances for certain wastes such as ditch seepage, deep percolation, and surface runoff.

Rhoades and Nelson (48) have set forth certain guides to use in irrigating corn. They state that frequency of irrigating will vary with water-holding capacity of the soil, the amount and distribution of rainfall, and the stage of plant growth.

It would be best to start the season with the soil moist to the maximum depth that corn roots will extend during the year. This, however, depends on the extent of rainfall during the winter months.

One should watch the soil moisture and plant symptoms and irrigate if the corn roots exhaust the soil moisture in the top 12 inches before tasseling or shows temporary leaf curling or wilting.

Apply enough water at each irrigation to fill the potential root zone to field-capacity. During the critical period just before tasseling and through pollination, less water may be needed in one irrigation because frequency and timing are of primary importance.

Adapted hybrids are essential to high-level production under irrigation. They must utilize the full growing season, withstand thick planting and respond to high levels of fertility.

Nitrogen is the element most frequently deficient in corn production. The use of nitrogen fertilizers at adequate rates is an essential part of irrigated corn production.

IX. EMPIRICAL FORMULAE FOR ESTIMATING ET. FROM METEOROLOGICAL DATA

There is a need to correlate evaporation from water and land surface and transpiration from plants with climatic factors and soil conditions. If longtime measurements of all the climatic factors affecting consumptive use were available, an empirical formula taking into account the effect of each factor could be developed and applied with reasonable accuracy for average conditions in any area (4).

The climatic factors believed to have the greatest effect on consumptive use on which data are generally available are temperature, relative humidity, precipitation, wind speed, and length of growing season. Several empirical formulae have been developed to use these data in estimating ET.

Blaney and Criddle Method

Blaney and Criddle (4, 5, 9, 39) developed an empirical formula showing the relationship between mean temperature, length of growing season, monthly per cent of annual daytime hours, and consumptive use of water. From this relationship, consumptive use of water by crops and irrigation requirement can readily be estimated for an area where the basic climatological data are available.

The procedure was developed by correlating measured consumptive use data with mean monthly temperatures, monthly per cent of yearly daytime hours, precipitation, and growing season. The coefficients they developed allow for the computation of consumptive use of each crop if the monthly temperature, latitude, and growing period of the crop are known and if the computed monthly per cent of annual daytime

hours are available.

Estimated seasonal consumptive use in inches can be computed from the formula

$$U = KF = \Sigma kf$$

where: U = use of water in inches for any period

K = predetermined empirical seasonal coefficient for each day

F = sum of monthly factors (f) for season, sum of product of mean monthly temperature (t) in °F, and monthly per cent of annual daytime hours (p). $\frac{t \times p}{100}$

Hargreaves Method

Hargreaves method for estimating ET. (9) is based upon the following assumptions: (1) evaporation of water is a physical process and can be computed, (2) an empirical relationship exists between computed evaporation and consumptive use of water by various crops. Mean monthly temperature, mean monthly relative humidity at noon and length of the days of the month are taken into consideration in computing evaporation. The formula is:

$$e = m\,(t-32)$$

where: e = monthly evaporation in inches

m = empirical factor

t = mean monthly temperature in °F.

Lowery-Johnson Method

The Lowery-Johnson method (9, 34, 39) utilizes accumulated heat units in day-degrees above 32° F, which are applied to an empirical

curve to determine annual consumptive use. Monthly distribution of the annual estimate is usually made by comparison with monthly evaporation rates. The formula is:

$$U = 0.8 + 0.156\ F$$

where: U = consumptive use in acre-feet per acre

F = effective heat in thousands of day degree F. (accumulation in day-degrees, of maximum daily temperature above 32° F. during the growing season).

They found a straight-line relation between annual consumptive use and heat supply from this formula.

Thornthwaite Method

The Thornthwaite method (39, 59) utilizes mean monthly temperature to determine monthly heat indexes for a certain area. The unadjusted values of P.E. are determined from a nomograph and then corrected for per cent of daytime hours.

$$\log P/E = \log 115 + 10/9 \log P - 10/9 \log (T-10)$$

where: P = average monthly precipitation in inches

E = evaporation

T = mean monthly temperature in °F.

Penman Method

The Penman method (9, 39, 44) is based on an estimate of radiant energy and includes corrections for wind speed, relative humidity, sunshine percentages, and uses a reflection coefficient. This method involves three formulas:

(1) $Ho = RA\ (1-r)(0.18 + 0.55\ n/N) - \sigma Ta^4\ (0.56 - 0.092\sqrt{ed})$

$(0.10 + 0.90\ n/N)$

(2) $Ea = 0.35\ (ea - ed)(1 + 0.0098U_2)$

(3) $E_T = \frac{\Delta H - 0.27Ea}{\Delta - 0.27}$

where: H = daily heat budget at surface in mm. water/day

RA = mean monthly extra terrestial radiation in mm. water/day

r = reflection coefficient

n = active duration of bright sunshine

N = maximum possible duration of bright sunshine

σ = Boltzman constant

σTa^4 = mm. water/day

ed = saturation vapor pressure at mean dew point in mm. Hg

Ea = evaporation in mm. water/day

ea = saturation vapor pressure at mean air temperature in mm. Hg

U_2 = mean wind speed at 2 meters above the ground in miles per day

ET. = evapotranspiration in mm. water/day

Atmometer Method

Black and white atmometers give a measure of intensity of radiation because white atmometers reflect more than 90 per cent of solar energy falling upon them and similar black atmometers absorb more than 50 per cent of solar energy, according to Munson (39). Various studies have indicated a high degree of correlation between mean monthly consumptive use of water and mean monthly differences

in evaporation between black and white atmometers.

X. ESTIMATING ET. FROM METEOROLOGICAL DATA

Studies at the Storrs, Connecticut Station (27) have been directed toward the development of a procedure for predicting the amount of water the soil will lose through transpiration from the plant and evaporation from the soil surface (ET.). The most promising of several procedures which have been investigated involves estimating P. E. from measuring the amount of solar energy received at plant height.

The maximum amount of water that can be removed from the soil as evapotranspiration depends to a large extent on the amount of sunshine or radiant energy received at plant height. Experiments have shown that the difference between the water loss from black and from white atmometers is directly proportional to the amount of sunshine (27). From this information the following formula has been developed to estimate P. E. by measuring the difference in water loss from black and white atmometers.

$$P.\ E. = 0.0229 + 0.0126\ (B-W)$$

If it is assumed that only that energy which falls on the plant is used in ET., then the value of P. E. multiplied by per cent cover gives corrected P. E.

Row crops seldom use water at the potential rate because of incomplete cover. There are additional refinements that can be added to increase accuracy. Most important is the inclusion of a factor for

the dryness of the soil. As soil dries out, the rate at which plants can extract water from the soil decreases. This becomes important when about 40 per cent of the water available for plant use has been extracted.

In addition to information on P. E., it is necessary to have data on water-holding capacity of the soil and the level of soil moisture which should be maintained for a particular crop.

According to Penman (43) evaporation is a physical process that must satisfy two basic requirements. There must be an energy supply to provide heat of vaporization; and there must be some transport mechanism for removing vapor. Combining these two concepts, it is possible to derive an expression of evaporation rate that depends only on the measurable weather elements.

By making some simplifying approximations, the weather data needed reduce to (1) duration of bright sunshine, (2) air temperature, (3) air humidity, and (4) wind speed. The quantity obtained is Eo, the evaporation rate for a hypothetical open water surface exposed to measured weather.

Three possible sources of energy for evaporation or ET. are solar radiation, heat that reaches the evaporating surface from the air, and heat that is stored in the evaporating body (60).

The sun is the basic source of all energy that is involved in the transferring of water from the liquid to the vapor phase. Not all of the energy received from the sun is used in evaporating water. Some of the incoming solar radiation is immediately reflected from the

surface back to the sky. For a surface covered with vegetation, the reflected radiation may constitute 25 per cent of the total incoming radiation. Also a certain per cent of the incoming radiation is radiated from the surface back to the sky; the amount depends on the earth's surface and on the sky above it. Often as much as 10 to 15 per cent of incoming radiation is lost in this manner (60).

After deducting the losses due to reflection and back radiation, the remainder (net radiation) can be partitioned into its various energy transformations and can be expressed by the energy balance or heat budget equation:

$$Rn = E + A + S + M$$

In this equation, E represents the amount of energy that goes into latent heat of vaporization; thus it is the ET. term (54). A represents the amount of energy that goes into heating the air, and is called sensible heat. S represents the storage of heat in the soil (or water) and storage in the vegetative volume when vegetation is present. M represents other miscellaneous energy terms such as energy exchanged in photosynthesis and respiration.

In general, one can conclude that the heat stored in the soil and a crop as thermal energy and the energy fixed photochemically, all account for a rather small proportion of the total daily energy transformations appearing as net radiation.

The proportionate distribution of energy balance between sensible and latent heat exchange with the atmosphere depends upon the availability of water for evaporation. When the soil surface

is wet, a relatively large proportion of the radiant energy is converted into evaporation, while sensible heat exchange is rather small (54). When the soil is very moist more than 80 per cent of net radiation is used in evaporation (60). Evaporation from a wet soil surface is often limited by energy supply (54). As the soil dries, the movement of water to the surface then becomes the limiting process.

When most crop plants are well supplied with water, most of the available water will be used in the transpiration process. If soil water either is unavailable to the plant, or if by some physiological mechanism, the plant restricts water vapor passage to the atmosphere, a larger proportion of radiant energy will go into sensible heat exchange at the expense of transpiration (54).

Soil moisture properties affect the E/Rn ratio in two ways. First, as soil water decreases, capillary conduction to the plant roots decreases, and moisture suction at the roots increases. This limits water supply to the plant and may induce stomatal closure and other physiological changes, such as leaf dessication, that affect transpiration. Second, capillary conduction to the soil surface is limited by decreased soil water. In the event that only partial plant cover exists, evaporation directly from the soil will decrease as the soil surface dries, even though moisture in the subsoil provides adequate moisture for continued high transpiration.

Several plant and soil factors interact to affect the direct evaporation of water from the soil and evaporation of water from plants as a result of the transpiration process. Soil factors include moisture

content, soil moisture suction, and water transmission characteristics. Plant factors include leaf area, root proliferation, plant type and perhaps physiological age (54). Fritschen and Van Bavel (15) concluded that the lower ET. rate from Sudangrass late in the season was not caused by physiological maturity, but rather appeared to be due to the fact that the seed heads absorbed the radiant energy, converted it into sensible heat, and also provided a very effective aerodynamic barrier against the transfer of sensible heat to the transpiring surfaces.

Since evaporation is a surface process, its rate is influenced by conditions within the liquid as well as by conditions that act from the gas-phase side (34). The vaporization pressure (water-vapor pressure) is the direct result of internal conditions. Its magnitude is determined by temperature of the water and by the influence of the non-aqueous materials dissolved or suspended in it or in contact with its surface. The corresponding actual vapor pressure of the gas phase immediately adjacent to the evaporating surface may be called the condensation pressure. When evaporation occurs, vaporization pressure (internal) exceeds condensation pressure (environmental).

Because both monthly mean temperature and P. E. depend upon the radiation, and because radiation has annual periodicity, monthly mean temperature and P. E. are highly correlated (34).

The empirical Thornthwaite equation for monthly estimates does include an adjustment for general variations of net radiation with latitude, but does not account for either lag of temperature behind

radiation (which arises from thermal storage by the soil), the effect of moisture availability in the region upon air temperature, or the larger effect of warm and cool advections on temperature than on heat exchange with the surface.

Janes (26) found that net radiation, as measured by a Gier and Dunkle radiometer, and the difference between loss of water from black and white atmometers were highly correlated. P. E. measured from Thornthwaite evapotranspirometer was slightly less than P. E. estimated from net radiation. P. E. was close to open pan evaporation. Actual P. E. measured from field grown crops varied from 69 to 90 per cent of the estimated P. E.

The ratio of measured ET. from corn to open pan evaporation was found to increase in a sigmoid manner prior to silking from a value of 0.36 at planting to 0.81 at silking (11). The value 0.81 remained constant for 16 days after silking and then declined, gradually at first, then rapidly. It was suggested that the changing ratio was due to increasing leaf area until silking and the declining physiological activity of the crop soon after commencement of ear growth.

Doss et al. (13) found that the ratio of ET. by corn to pan evaporation varied from 0.38 at emergence to 1.12 during early dough stage, then declined to 0.95 at grain maturity.

McWhorter and Bruce (37) found open pan evaporation highly correlated with evaporation from black and white atmometers as well as their difference. Likewise, they found atmometer evaporation and solar radiation to be highly correlated. Following is a sample

of their correlation coefficients:

Black-white with radiation	r = 0.923**
Black with radiation	r = 0.923**
White with radiation	r = 0.820**
Black-white with open pan	r = 0.825**
Black with open pan	r = 0.824**
White with open pan	r = 0.761**

They showed that pan evaporation may be estimated from atmometer evaporation and that the difference in evaporation from black and white atmometers is a good method of measuring solar radiation.

High correlations were found by Drinkwater and Janes (14) between measured P. E. of bluegrass and open-pan evaporation, atmometer evaporation, average temperature, solar radiation, and duration of sunshine when data were grouped into between-rain periods.

Potometer experiments on transpiration of plants of various kinds conducted by Briggs and Shantz (6, 7) are among the most extensive of their kind. They indicate a very close correlation between transpiration and meteorological phenomena, including evaporation from water surfaces, air temperatures, solar radiation, wet-bulb depression, and wind speed.

Halkias et al. (19) found a very good correlation existed between evaporation from a white atmometer and open pan evaporation. They state that black and white atmometers have proven to be excellent instruments for the purpose of estimating use of water by crops. The difference in evaporation between black and white atmometers has shown a very high correlation with use of water by crops as well as with solar radiation, as measured by an Eppley pyrheliometer. A sample of

their calculations are:

1. Open pan evaporation in inches = 0.0051 evaporation from atmometer in cc.
2. Mean monthly difference in evaporation between black and white atmometers in cc. = 0.028 mean monthly radiation in gm. cal./sq. cm.

CHAPTER III

MATERIALS AND METHODS

Experiments to ascertain the effect of various soil moisture levels on yield response to applied nitrogen on corn, were conducted at the Tennessee Agricultural Experiment Stations at Knoxville and Jackson in 1962 and 1963.

Three moisture levels, viz. no irrigation, and irrigations at two atmospheres tension and at five atmospheres tension; and six nitrogen levels, viz. 0, 60, 120, 180, 240 and 300 pounds per acre were under study in a split plot design with irrigations as main plots and nitrogen levels as subplots. There were three replications. The size of main plots was 120 by 35 feet at Knoxville and 60 by 70 feet at Jackson. The subplots were 20 by 35 feet.

Nitrogen was applied in the form of ammonium nitrate. Five hundred pounds of 0-20-20 fertilizer was applied per acre to supply additional phosphorus and potassium. All fertilizers were broadcast and disked in. Dixie 29 corn was planted on ridges 30 inches between rows. The plant population was adjusted to 20,000 plants per acre. Furrow irrigation was used in the irrigated treatments.

Meteorological data noted below were taken from the weather stations located at each of the experiment stations.

1. Daily maximum and minimum temperatures noted in weather box (cotton region shelter).

2. Daily dry and wet bulb temperature noted in the weather box, from which relative humidity and dew point were calculated using standard psychrometeric tables (36).
3. Air movement noted by a totalizing anemometer.
4. Open pan evaporation (Standard United States Weather Bureau Pan).
5. Solar radiation measurements recorded with Pyrheliograph at Jackson.
6. Evaporation from black and white Livingston atmometer bulbs.
7. Sunrise and sunset records from World Almanac (68).

In addition to the above data, in 1963 small weather stations were placed within the crop to measure maximum and minimum temperatures and evaporation from atmometers. The plots receiving 120 pounds of nitrogen and receiving no irrigations and irrigations at 2 atmospheres tension were selected from two replications for these observations. In each plot a small weather station was located and the following equipment was installed:

1. One black and one white Livingston atmometer at a height of five feet above ground level.
2. One black and one white Livingston atmometer at 18 inches above ground level.
3. One small weather box containing one maximum and one minimum thermometer at five feet above ground level.
4. One weather box containing one maximum and one minimum thermometer at 18 inches above ground level in one replication.

At Knoxville, maximum and minimum temperatures at 18 inches above ground level were noted in only one plot. The temperatures within the crop were read every day excluding week-ends at Knoxville and on alternate days at Jackson.

The water loss from atmometer bulbs was determined by the amount of water required to refill the reservoir bottles. These observations were noted on alternate week-days during the period of observation. Since all atmometer bulbs used in these experiments had a uniform evaporation coefficient of 0.77, the observations of water loss were not adjusted but the original readings were used for all calculations.

In each plot, selected as described above, one aluminum access tube two inches in diameter was fixed into the soil to a depth of 54 inches. The soil moisture was determined by the neutron scattering technique at six-inch intervals to a depth of 54 inches. The surface moisture to a depth of nine inches was determined by the surface moisture probe. The readings were noted on Monday and Friday of every alternate week except when the plots were inaccessible due to rain. The differences in moisture in the soil profile between two successive readings plus the rainfall and/or irrigation water added during the period was taken to be the measured or actual ET. As there were no irrigations at Knoxville in 1963, the average of four plots was taken for calculating the correlations. Similarly at Jackson in both years and at Knoxville in 1962, the average ET. of the two plots receiving no irrigations and the two plots receiving irrigations were taken to be the measured or actual ET. under unirrigated and irrigated

conditions, respectively.

All within-crop observations were started shortly after emergence of the crop and continued until its maturity, i.e., 120 days.

The data was processed through the IBM 1620 Computer using the Stepwise Regression Analysis Program (STRAP) for the yield, drouth-day, and nitrogen data and Bob Ling's Multiple Regression Program for the meteorological data.

Some of the physical characteristics of the soil types under which these experiments were conducted are summarized in Table I.

I. NEUTRON MOISTURE METER

The neutron equipment has been proven to be sufficiently accurate and quick for measuring the soil moisture. The equipment used in this study was made by Nuclear-Chicago Corporation, Des Plaines, Illinois.

Equipment Used

1. Model 2800 portable scaler
2. Model P-19 subsurface soil moisture probe
3. Model P-21 surface soil moisture probe

A detailed description of the internal structure and working of these instruments has been given by Kuranz (31).

In theory, moisture measurements by the nuclear method are based on physical laws governing the scattering and moderation of high energy neutrons by the hydrogen atom in water and consequent yield of

TABLE I

SOME PHYSICAL CHARACTERISTICS OF SEQUATCHIE AND MEMPHIS SOILS ON WHICH EXPERIMENTS WERE CONDUCTED

A. SEQUATCHIE LOAM

Soil depth	0-6 inches		6-12 inches	
Bulk density	1.31		1.47	
	Soil moisture %		Soil moisture %	
Moisture tension	Weight basis	Volume basis	Weight basis	Volume basis
1/3 atmosphere	29.68	38.88	31.76	46.69
1 atmosphere	21.51	28.18	25.19	37.03
2 atmospheres	20.00	26.20	22.38	32.90
5 atmospheres	15.41	20.19	17.68	25.99
7 atmospheres	14.49	18.98	16.50	24.25
15 atmospheres	11.35	14.87	13.64	20.05

B. MEMPHIS SILT LOAM

Soil depth	0-6 inches		6-12 inches	
Bulk density	1.33		1.38	
	Soil moisture %		Soil moisture %	
Moisture tension	Weight basis	Volume basis	Weight basis	Volume basis
1/3 atmosphere	24.4	32.4	26.1	36.0
2 atmospheres	9.0	12.0	16.7	23.0
5 atmospheres	6.5	8.6	12.8	17.7
9 atmospheres	5.5	7.3	10.9	15.0

slow neutrons detected by the $B^{10} F_3$ counter, which is sensitive only to slow neutrons. The B^{10} absorbs slow neutrons and in doing so emits alpha particles which set off the counter and produces an electrical impulse that is recorded on the scaler.

The moderation of fast neutrons to slow neutrons is directly proportional to the number of hydrogen atoms contained in the soil. This is true because the average energy loss by fast neutrons is much greater in collisions with atoms of low atomic weight than in collisions involving heavier atoms, and hydrogen is the only element of low atomic weight found in most inorganic materials. Stolzy and Cahoon (51) have shown that a definite curvilinear relationship exists between per cent of water in the soil and the meter reading.

The calibration curves supplied for the moisture probe are for inorganic soils whose hydrogen content is primarily that of the water molecule. Many investigators have found that a single calibration curve will be sufficient for all soils, except those extremely high in sand or organic matter (16, 32, 52, 53). We have few such soils in Tennessee.

II. LIVINGSTON ATMOMETER

The atmometers used in this experiment were of the spherical type designed and described by Dr. B. E. Livingston (34). These atmometers were also described by Halkias *et al.* (19) and McWhorter and Bruce (37).

CHAPTER IV

RESULTS AND DISCUSSIONS

No attempt was made in this phase of the study to correlate the climatic factors measured within the crop since only one year's data were available and these results have been summarized by Kulkarni (31). He found no appreciable difference in the correlation of atmometer evaporation and temperatures with ET. or open pan evaporation whether measured within or outside the crop. His results indicated that cumulated ET. was highly correlated with evaporation from open pan and with evaporation from atmometer bulbs.

From indirect estimates of net radiation from the difference in water loss from black and white atmometers ("B-W"), he showed that from about 45 days after planting up to maturity approximately 71 to 75 per cent of the total net energy received on the top of the crop, reached the ground level.

He concluded that the prediction of ET. based upon the "B-W" from atmometers placed outside the crop was equal or superior to the use of open pan evaporation.

In this phase of the study, which includes data for 1962 and 1963, correlations were obtained between ET. and climatic variables measured outside the crop on a cumulative basis only. In addition, correlations were obtained between corn yields, nitrogen levels, and drouth-days as derived from ET.

Correlations were calculated between the water loss from open pan and ET. under six sets of conditions, viz. no irrigation, irrigation at two atmospheres tension, no nitrogen, 120 pounds of nitrogen per acre, 300 pounds of nitrogen per acre, and average ET. for all treatments. Open pan evaporation was highly correlated with ET. under all treatments, with no significant difference being found among treatments. Correlations were then obtained between average ET. and the meteorological elements such as "B-W", maximum and mean temperatures, relative humidity, dew point temperature, sunshine hours, wind speed, and solar radiation.

Correlations were also calculated between water loss from open pan and "B-W", mean temperature, and wind speed.

The results of the correlations and regressions are shown in Table II for the data at Knoxville and Table III for the data at Jackson.

A curve could be fitted with the observed values of the independent and dependent variables. In no case did the quadratic function prove superior to the linear function.

I. CORRELATIONS OF CUMULATED WATER LOSS FROM OPEN PAN WITH CUMULATED ET. UNDER VARIOUS TREATMENTS

The cumulated ET. from all treatments was found to be significantly correlated at the 0.05 level of probability with water loss from open pan at both Knoxville and Jackson. The treatment did not appear to appreciably affect the degree of correlation. Although the

TABLE II

COEFFICENTS OF CORRELATIONS, VALUES OF r^2 AND R^2, STANDARD ERRORS OF REGRESSION COEFFICIENTS, STANDARD ERRORS OF ESTIMATE, AND EQUATIONS DESCRIBING THE RELATIONSHIP BETWEEN THE VARIABLES UNDER STUDY, IN CORN ON A SEQUATCHIE SOIL, AT THE AGRICULTURAL EXPERIMENT STATION AT KNOXVILLE

Variables	Coefficients of correlation r	r^2 or R^2	Standard error of regression coefficient	Standard error of the estimate	Equation describing dependent variable (Y) as a function of independent variable (X)
Y = Cumulative water loss from open pan in inches					
X1 Cumulative ET. in acre inches; no irrigation	0.9651	0.9314	0.0412	0.1821	$\hat{Y} = 0.4327 + 0.5083X$
X2 Cumulative ET. in acre inches; irrigated at 2 atmospheres tension	0.9834	0.9672	0.0314	0.1389	$\hat{Y} = -0.5988 + 0.6001X$
X3 Cumulative ET. in acre inches; no nitrogen	0.9802	0.9609	0.0327	0.1445	$\hat{Y} = -0.2756 + 0.5620X$
X4 Cumulative ET. in acre inches; 120 lb. nitrogen	0.9760	0.9526	0.0379	0.1678	$\hat{Y} = -0.3685 + 0.5928X$

TABLE II (continued)

Variable	Coefficients of correlation r	r^2 or R^2	Standard error of regression coefficient	Standard error of the estimate	Equation describing dependent variable (Y) as a function of independent variable (X)
X5 Cumulative ET. in acre inches; 300 lb. nitrogen	0.9798	0.9599	0.0341	0.1508	$\hat{Y} = -0.4492 + 0.5839X$
X6 Cumulative ET. in acre inches; average all treatments	0.9787	0.9580	0.0348	0.1541	$\hat{Y} = -0.3650 + 0.5796X$
Y = Cumulative average ET. in acre inches					
X1 Cumulative "B-W" in ml. outside the crop	0.9802	0.9608	0.0006	0.1488	$\hat{Y} = -0.0466 + 0.0110X$
X2 Cumulative daily maximum temperatures in °F.	0.9976	0.9953	0.00004	0.5152	$\hat{Y} = -0.8285 + 0.0020X$
X3 Cumulative daily mean temperatures in °F.	0.9971	0.9942	0.0001	0.5702	$\hat{Y} = -0.7106 + 0.0024X$
X4 Cumulative daily dew point temperatures in °F.	0.9717	0.9443	0.0002	0.1773	$\hat{Y} = 0.6321 + 0.0025X$

TABLE II (continued)

	Variables	Coefficients of correlation r	r^2 or R^2	Standard error of regression coefficient	Standard error of the estimate	Equation describing dependent variable (Y) as a function of independent variable (X)
X5	Cumulative relative humidity percentages	0.9985	0.9970	0.00003	0.4129	$\hat{Y} = -1.1262 + 0.0021X$
X6	Cumulative daily sunshine hours	0.9988	0.9976	0.0002	0.3681	$\hat{Y} = -1.0637 + 0.0125X$
X7	Cumulative daily wind speed in miles	0.9614	0.9243	0.0003	0.2067	$\hat{Y} = 0.1538 + 0.0037X$
X8	Cumulative daily mean temperatures in °F. X cumulative daily sunshine hours	0.9958	0.9916	0.000004	0.6901	$\hat{Y} = -0.7734 + 0.0002X$
X9	Cumulative daily total solar radiation in gram calories per cm^2	0.9933	0.9867	0.00001	0.8664	$\hat{Y} = -1.5178 + 0.0004X$
X10	Multiple-cumulative mean temperatures, dewpoint; wind speed, and sunshine hours	0.9992	0.9984	0.0007 0.0003 0.0003 0.0047	0.2971	$\hat{Y} = -0.5656 + 0.0025X1 + 0.0011X2 - 0.0004X3 - 0.0045X4$

TABLE II (continued)

Variables	Coefficients of correlation r	r^2 or R^2	Standard error of regression coefficient	Standard error of the estimate	Equation describing dependent variable (Y) as a function of independent variable (X)
Y = Cumulative evaporation from open pan in inches					
X1 Cumulative "B-W" in ml. outside the crop	0.9368	0.8777	0.0019	0.4519	$\hat{Y} = 3.222 + 0.0162X$
X2 Cumulative daily mean temperature in °F.	0.9901	0.9803	0.0002	0.1816	$\hat{Y} = 0.5816 + 0.0038X$
X3 Cumulative daily wind speed in miles	0.9071	0.8228	0.0008	0.5439	$\hat{Y} = 4.3485 + 0.0053X$
X4 Multiple-cumulative relative humidity percentages, wind speed, and degree-sunshine hours	0.9979	0.9958	0.0019 0.0005 0.0001	0.8325	$\hat{Y} = 0.8764 + 0.0028X1$ $-0.0028X2 + 0.0002X3$

TABLE III

COEFFICIENTS OF CORRELATIONS, VALUES OF r^2 AND R^2, STANDARD ERRORS OF REGRESSION COEFFICIENTS, STANDARD ERRORS OF ESTIMATE, AND EQUATIONS DESCRIBING THE RELATIONSHIP BETWEEN THE VARIABLES UNDER STUDY, IN CORN ON A MEMPHIS SOIL, AT THE AGRICULTURAL EXPERIMENT STATION AT JACKSON

Variables	Coefficients of correlation r	r^2 or R^2	Standard error of regression coefficient	Standard error of the estimate	Equation describing dependent variable (Y) as a function of independent variable (X)
Y = Cumulative water loss from open pan in inches					
X1 Cumulative ET. in acre inches; no irrigation	0.9879	0.9760	0.0286	0.1106	$\hat{Y} = -0.5632 + 0.6442X$
X2 Cumulative ET. in acre inches; irrigated at 2 atmospheres tension	0.9897	0.9795	0.0319	0.1236	$\hat{Y} = -1.5268 + 0.8051X$
X3 Cumulative ET. in acre inches; no nitrogen	0.9926	0.9852	0.0237	0.9194	$\hat{Y} = -0.9777 + 0.6958X$
X4 Cumulative ET. in acre inches; 120 lb. nitrogen	0.9932	0.9863	0.0232	0.8991	$\hat{Y} = -1.2495 + 0.717X$

TABLE III (continued)

Variable	Coefficients of correlation r	r^2 or R^2	Standard error of regression coefficient	Standard error of the estimate	Equation describing dependent variable (Y) as a function of independent variable (X)
X5 Cumulative ET. in acre inches; 300 lb. nitrogen	0.9903	0.9808	0.0286	0.1107	$\hat{Y} = -1.4300 + 0.7456X$
X6 Cumulative ET. in acre inches; average all treatments	0.9922	0.9844	0.0250	0.9681	$\hat{Y} = -1.2193 + 0.7195X$
Y = Cumulative average ET. in acre inches					
X1 Cumulative "B-W" in ml. outside the crop	0.9769	0.9544	0.0005	0.1654	$\hat{Y} = 0.0288 + 0.0076X$
X2 Cumulative daily maximum temperatures in °F.	0.9984	0.9967	0.00003	0.4430	$\hat{Y} = 0.11759 + 0.0021X$
X3 Cumulative daily mean temperature in °F.	0.9984	0.9969	0.00004	0.4315	$\hat{Y} = -1.1084 + 0.0024X$
X4 Cumulative daily dew point temperature in °F.	0.9986	0.9972	0.00004	0.4106	$\hat{Y} = -0.9245 + 0.0027X$

TABLE III (continued)

	Variable	Coefficient of correlation r	r^2 or R^2	Standard error of regression coefficient	Standard error of the estimate	Equation describing dependent variable (Y) as a function of independent variable (X)
X5	Cumulative relative humidity percentages	0.9968	0.9935	0.00005	0.6234	$\hat{Y} = -1.4850 + 0.0023X$
X6	Cumulative daily sunshine hours	0.9984	0.9969	0.0002	0.4316	$\hat{Y} = -1.4751 + 0.0129X$
X7	Cumulative daily wind speed in miles	0.7003	0.4904	0.0007	0.5529	$\hat{Y} = 9.5275 + 0.0008X$
X8	Cumulative daily mean temperatures in °F. X cumulative daily sunshine hours	0.9987	0.9975	0.000002	0.3875	$\hat{Y} = -0.9419 + 0.0002X$
X9	Cumulative daily total solar radiation in grams calories per cm^2	--	--	--	--	--
X10	Multiple-cumulative mean temperatures, dew point, wind speed, and sunshine hours	0.9991	0.9983	0.0038 0.0040 0.00005 0.0048	0.3205	$\hat{Y} = -0.6100 - 0.0153X1 + 0.0167X2 + 0.0002X3 + 0.0138X4$

TABLE III (continued)

	Variable	Coefficient of correlation r	r^2 or R^2	Standard error of regression coefficient	Standard error of the estimate	Equation describing dependent variable (Y) as a function of independent variable (X)
Y =	Cumulative evaporation from open pan in inches					
X1	Cumulative "B-W" in ml. outside the crop	0.9927	0.9855	0.0004	0.1359	$\hat{Y} = 1.5120 + 0.0107X$
X2	Cumulative daily mean temperatures in °F.	0.9942	0.9884	0.0001	0.1214	$\hat{Y} = 0.5672 + 0.0033X$
X3	Cumulative daily wind speed in miles	0.7619	0.5805	0.0009	0.7299	$\hat{Y} = 13.6294 + 0.0016X$
X4	Multiple-cumulative relative humidity percentages, wind speed, and degree-sunshine hours	0.9997	0.9994	0.0005 0.0001 0.00004	0.2867	$\hat{Y} = 1.5987 - 0.0043X1 + 0.0002X2 + 0.0005X3$

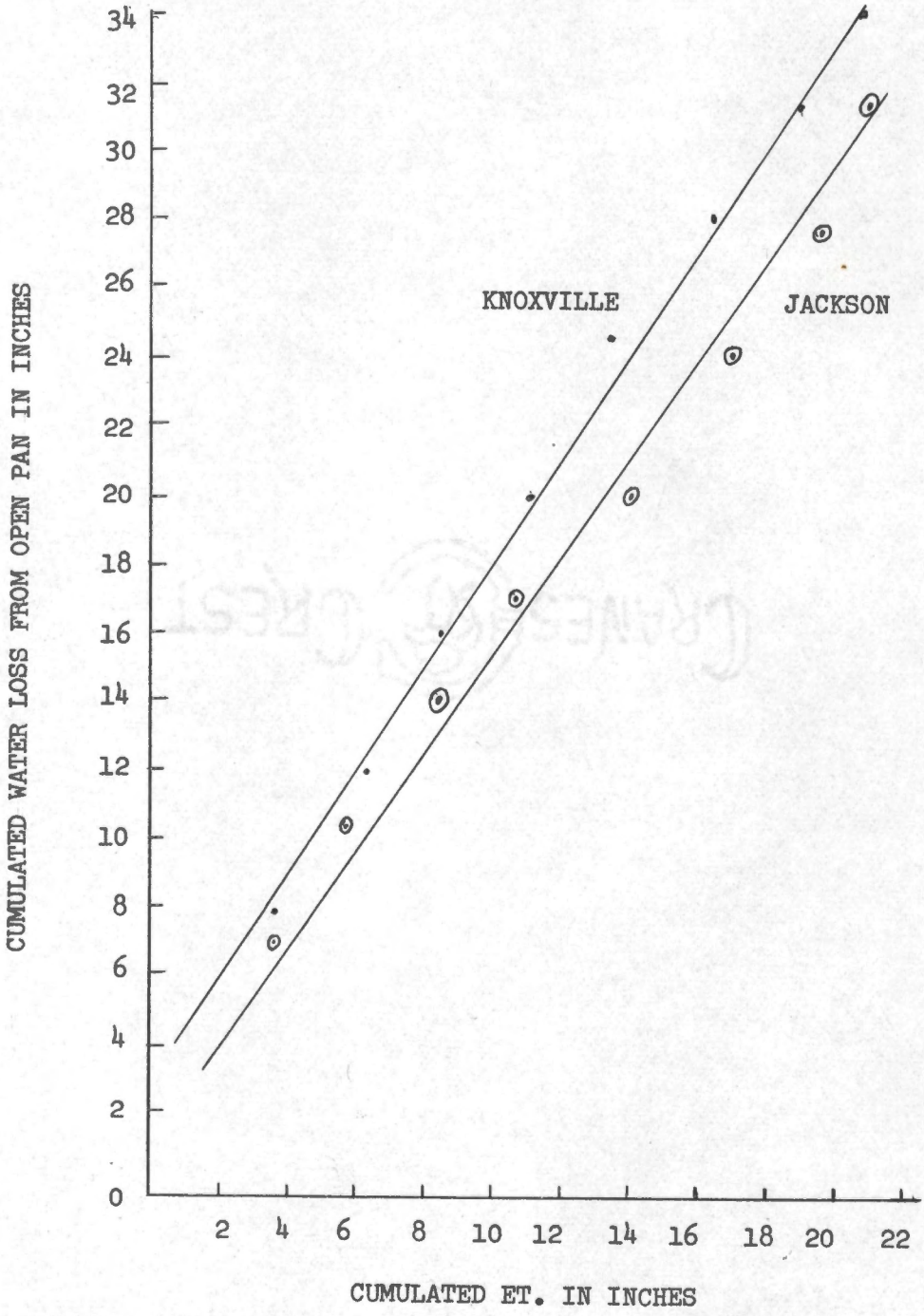


Figure 1. Relationship between average ET. in corn and water loss from open pan at Knoxville and Jackson.

correlation coefficients were slightly higher for the data at Jackson, the standard errors of estimate were also higher as compared to that for Knoxville (Tables II and III).

II. CORRELATIONS OF CUMULATED AVERAGE ET. WITH CUMULATED WATER LOSS FROM ATMOMETERS

At both locations, significant correlations at the 0.05 level of probability were observed between the cumulated average ET. and the differences in water loss from black and white atmometers (B-W). At Knoxville the correlation coefficient was slightly higher and the standard error of estimate slightly smaller than that at Jackson (Tables II and III).

At Knoxville, the use of "B-W" proved superior to the use of water loss from open pan as a means of estimating ET., having a higher correlation coefficient and a smaller standard error of estimate. Although the correlation coefficient for water loss from open pan is slightly higher than that for "B-W" at Jackson, the standard error of estimate is much greater. These results indicate that for estimating ET., use of "B-W" is equal or superior to the use of water loss from open pan.

III. CORRELATIONS OF CUMULATED AVERAGE ET. WITH CUMULATED TEMPERATURES AND RELATIVE HUMIDITY

Both at Knoxville and Jackson, the cumulated average ET. was found to be significantly correlated at the 0.01 level of probability

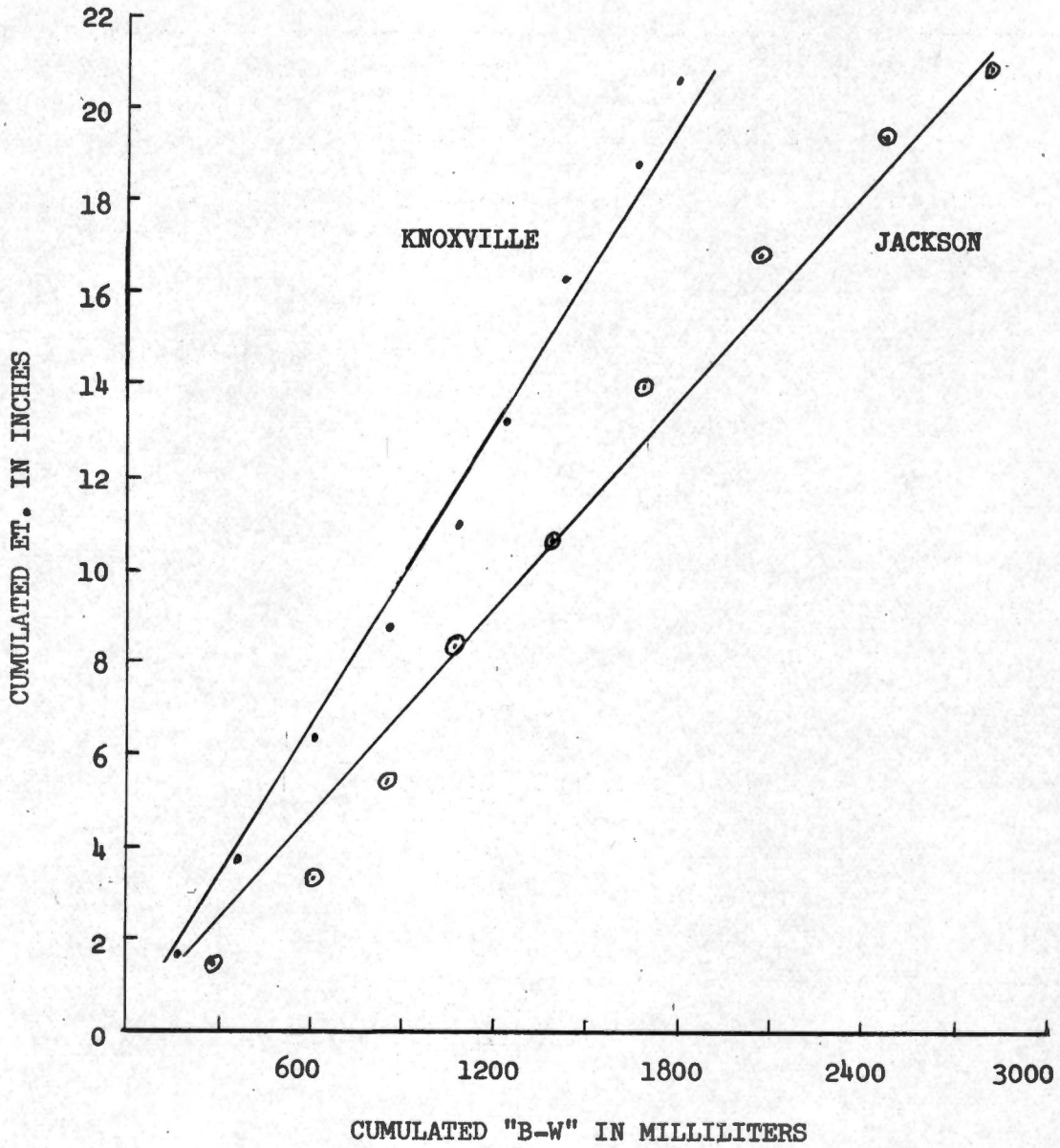


Figure 2. Relationship between water loss from "B-W" and ET. in corn at Knoxville and Jackson.

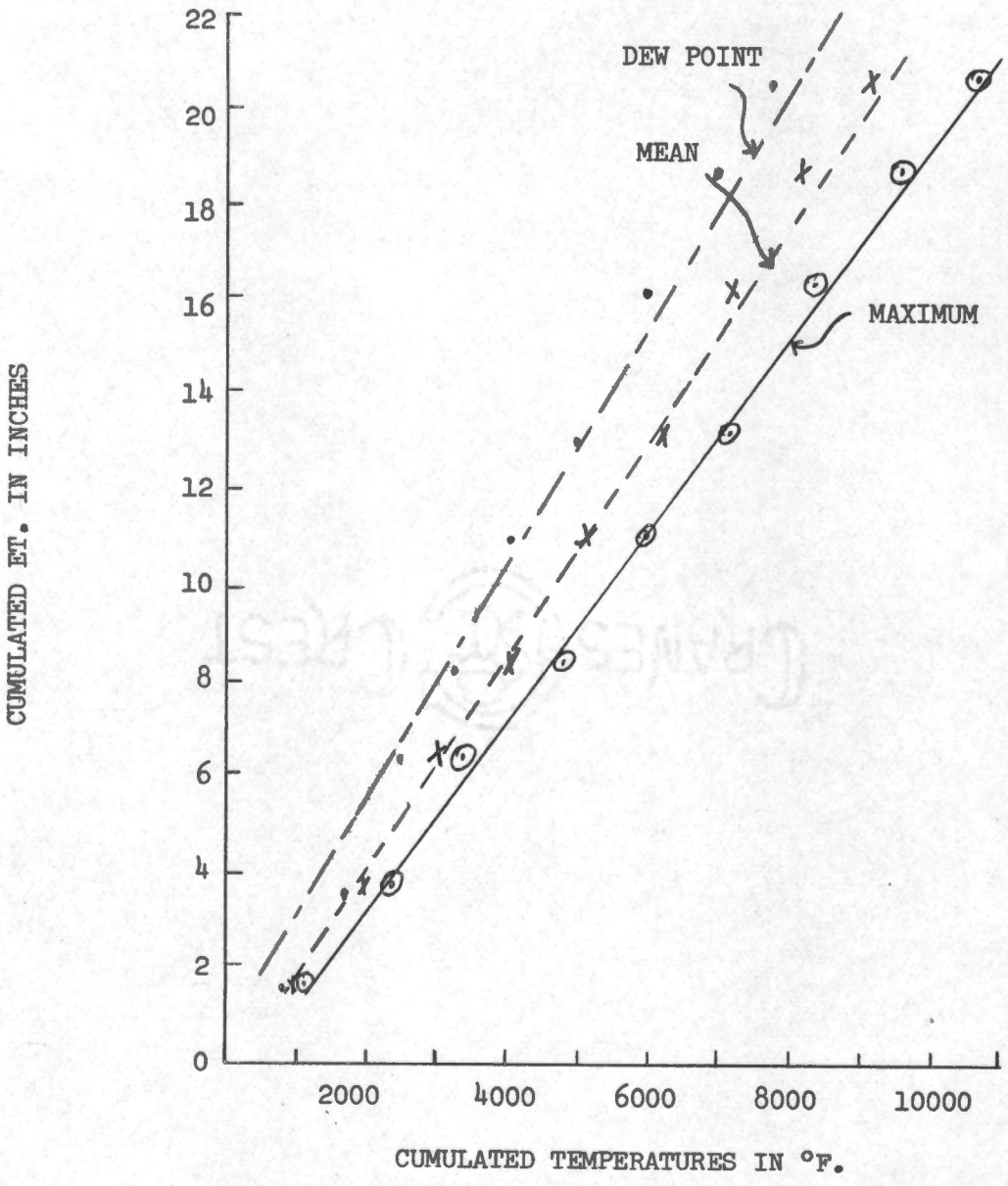


Figure 3. Relationship between maximum, mean and dew point temperatures and ET. in corn at Knoxville.

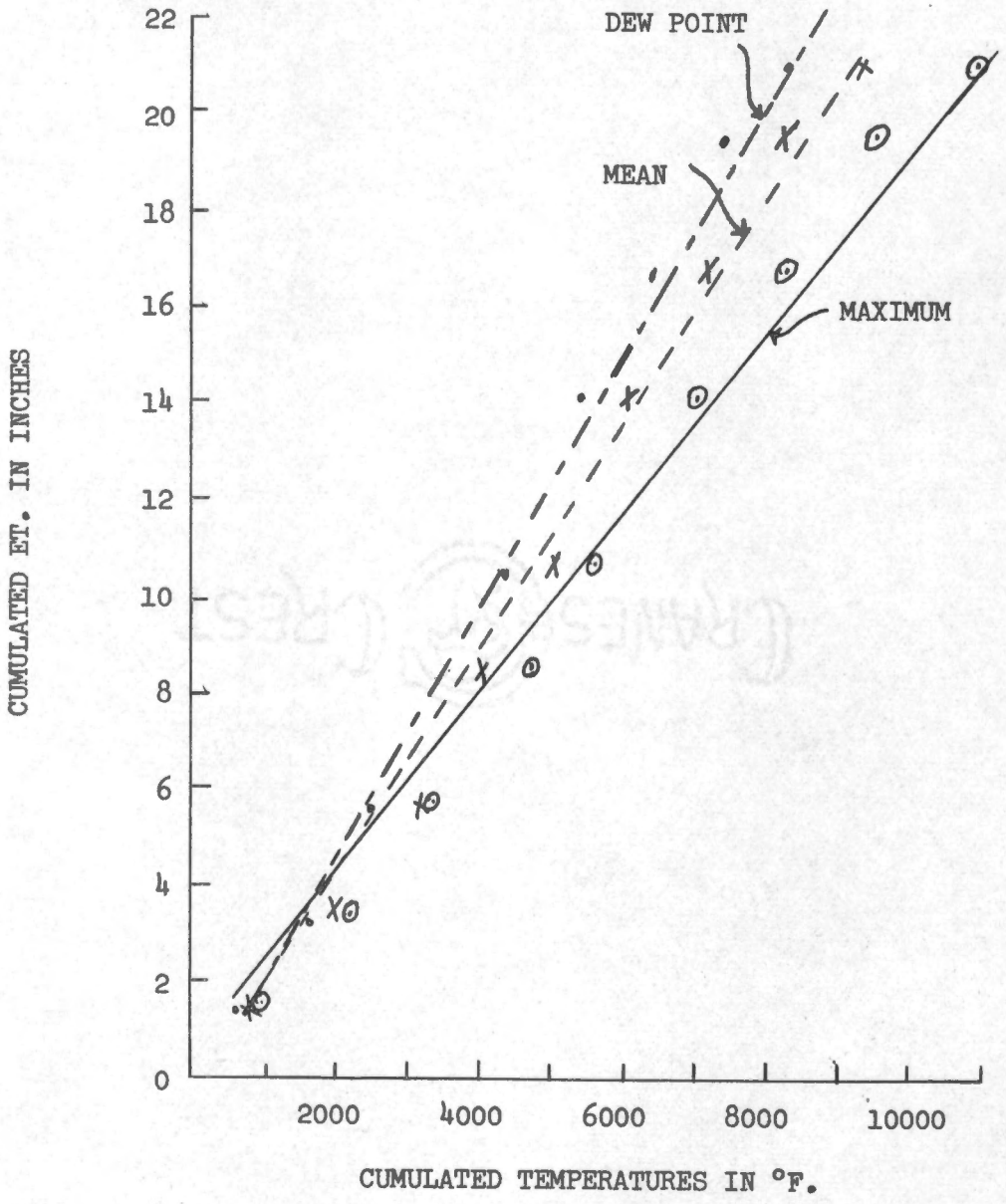


Figure 4. Relationship between maximum, mean and dew point temperatures and ET. in corn at Jackson.

with cumulated maximum, mean, and dew point temperatures, and relative humidity. At Knoxville, the coefficients were 0.0020, 0.0024, 0.0025, and 0.0021 for cumulated maximum, mean, and dew point temperatures, and relative humidity, respectively. The coefficients at Jackson were 0.0021, 0.0024, 0.0027, and 0.0023 for cumulated maximum, mean, and dew point temperatures, and relative humidity, respectively. Strikingly enough, the coefficients were not found to vary appreciably either in absolute magnitude or in relative magnitude for the two locations.

The correlation coefficients were found to be very high and the standard errors of estimate relatively small.

IV. CORRELATIONS OF CUMULATED AVERAGE ET. WITH CUMULATED SUNSHINE HOURS, DEGREE-SUNSHINE HOURS, WIND SPEED, AND TOTAL SOLAR RADIATION AT KNOXVILLE

The correlations of cumulated ET. with cumulated sunshine hours, cumulated degree-sunshine hours, and cumulated total solar radiation were significant at the 0.01 level of probability and with wind speed at the 0.05 level of probability. When multiple regressions were calculated with mean temperature, dew point temperature, wind speed, and sunshine hours the correlation coefficient was increased (0.9992) and the standard error of estimate was decreased (0.2971) (Table II).

V. CORRELATIONS OF CUMULATED AVERAGE ET. WITH CUMULATED SUNSHINE HOURS, DEGREE-SUNSHINE HOURS, AND WIND SPEED AT JACKSON

The correlations of cumulated ET. with cumulated sunshine hours

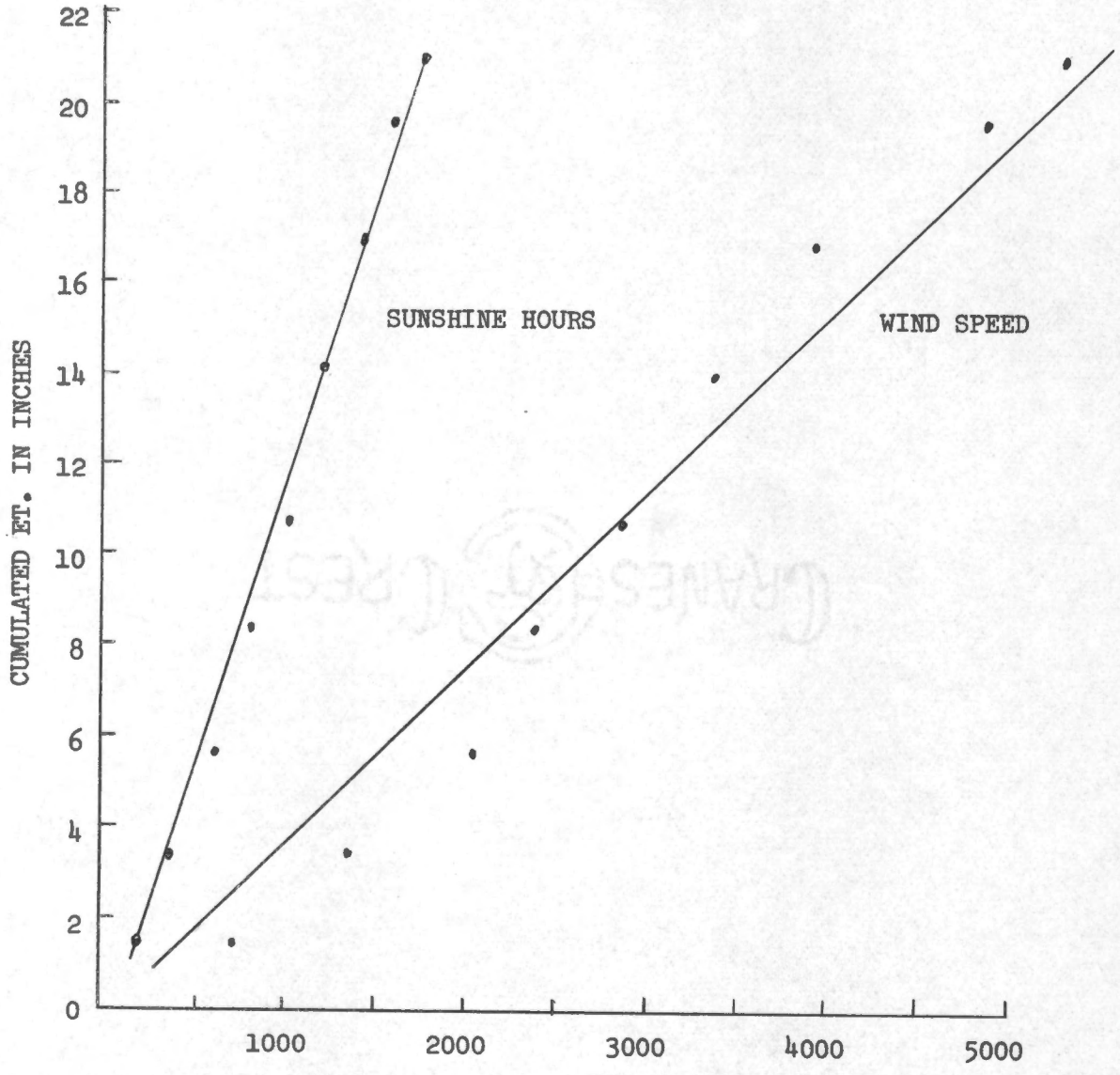


Figure 5. Relationship between sunshine hours, wind speed and ET. in corn at Knoxville.

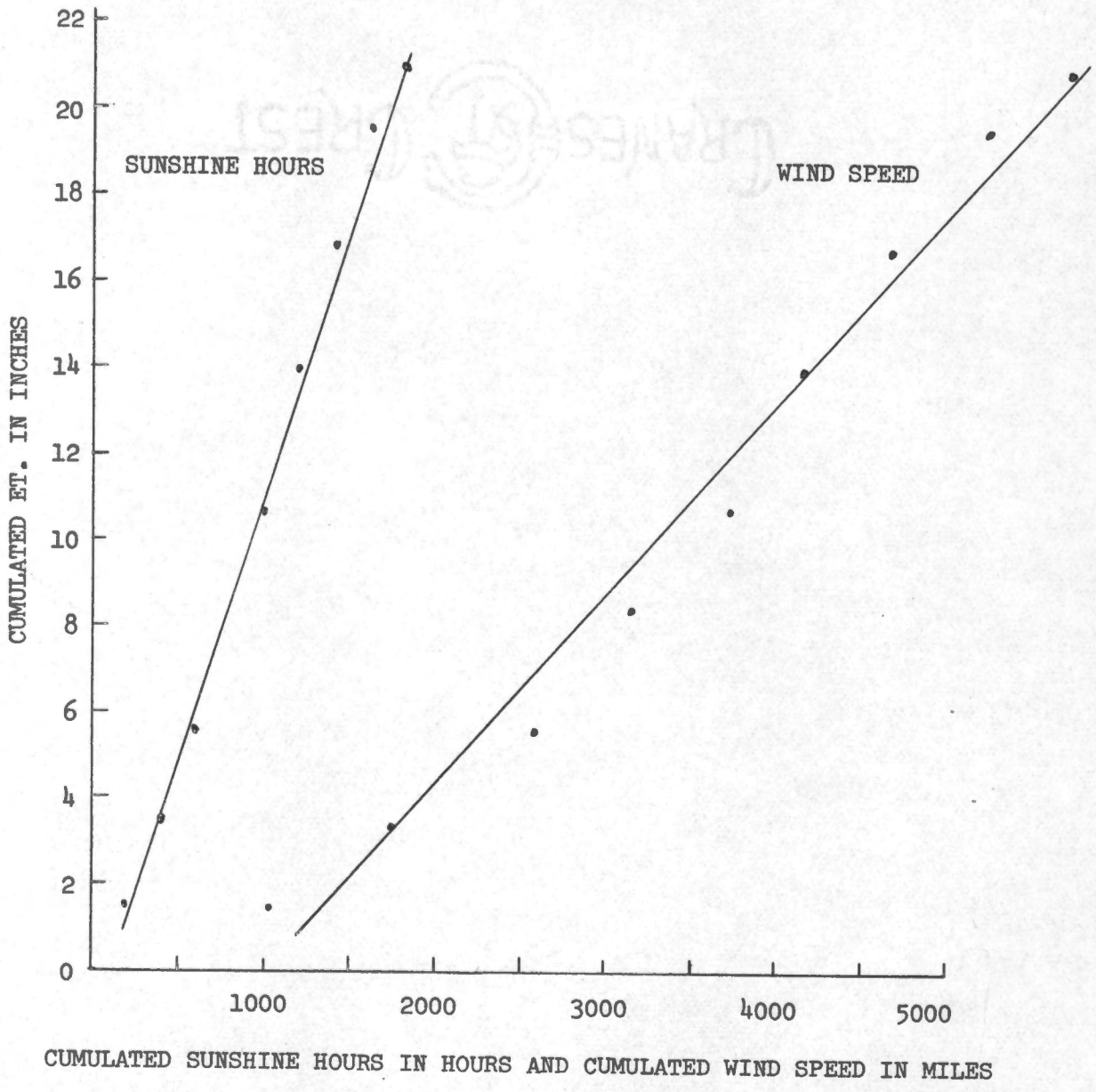


Figure 6. Relationship between sunshine hours, wind speed and ET. in corn at Jackson.

and cumulated degree-sunshine hours were significantly correlated at the 0.01 level of probability. The correlations of cumulated ET. with cumulated wind speed were considerably lower, however (0.7003) (Table III). This is as would be expected since wind speed alone cannot be an important factor governing ET. under these conditions. It was somewhat surprising that sunshine hours alone were so highly correlated with ET. When multiple regressions were calculated with mean temperature, dew point temperature, wind speed, and sunshine hours the correlation coefficient was increased (0.9991) and the standard error of estimate was decreased (0.3205) (Table III) as was the case at Knoxville. Except for wind speed, the coefficients of correlation were quite similar at both locations, however, the standard errors of estimate were consistently higher at Jackson than at Knoxville. Total solar radiation data were not complete for Jackson.

VI. CORRELATIONS OF CUMULATED WATER LOSS FROM OPEN PAN WITH CUMULATED WATER LOSS FROM ATMOMETERS AND OTHER METEOROLOGICAL FACTORS

The cumulated water loss from open pan was found to be correlated significantly with "B-W" at the 0.01 level of probability at Jackson and at the 0.10 level of probability at Knoxville. The corresponding standard errors of estimate were 0.1359 and 0.4519, respectively (Tables II and III). The cumulated water loss from open pan was highly correlated with cumulated mean temperature at both Knoxville and Jackson with correlation coefficients of 0.9901 and 0.9942, respectively.

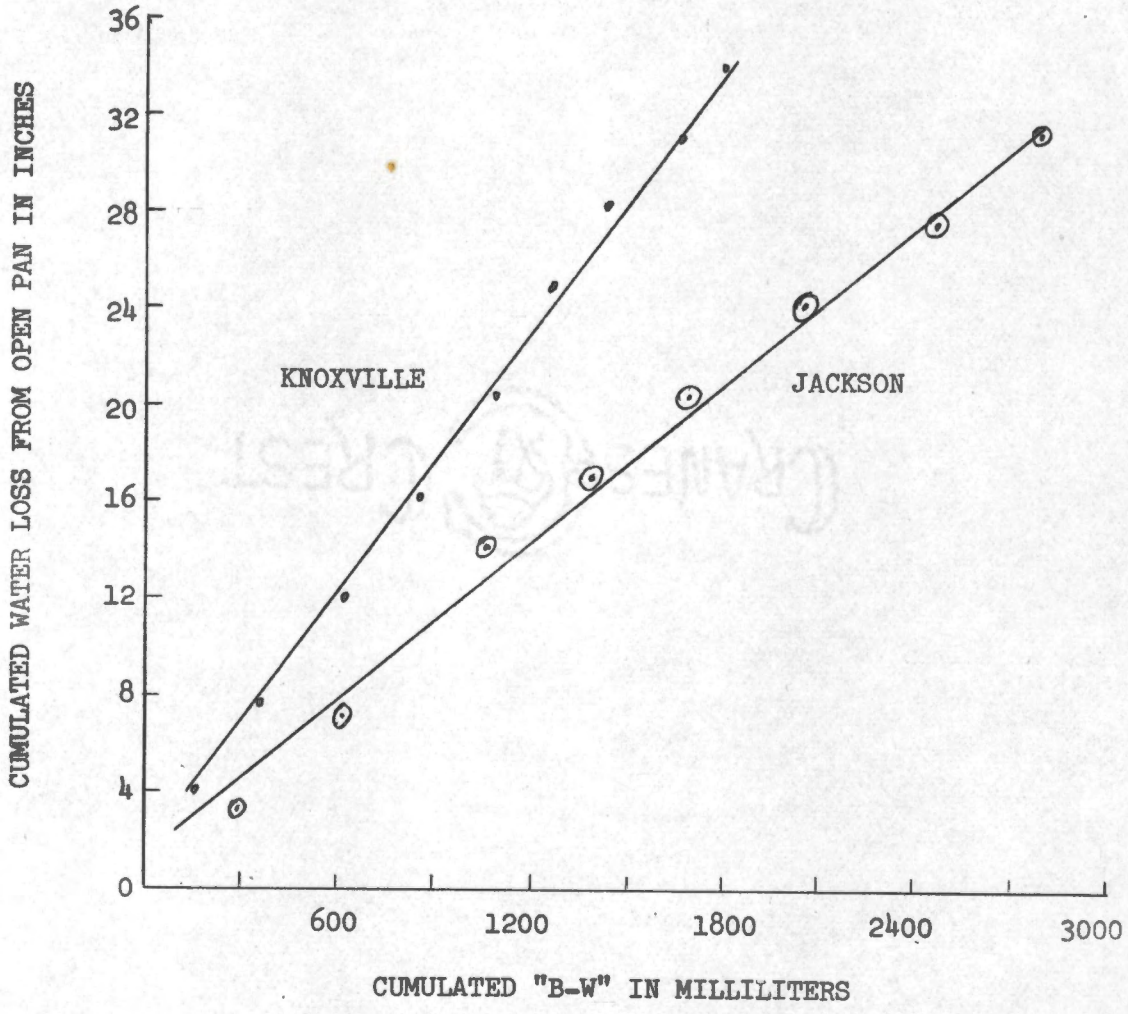


Figure 7. Relationship between water loss from "B-W" and from open pan at Knoxville and Jackson.

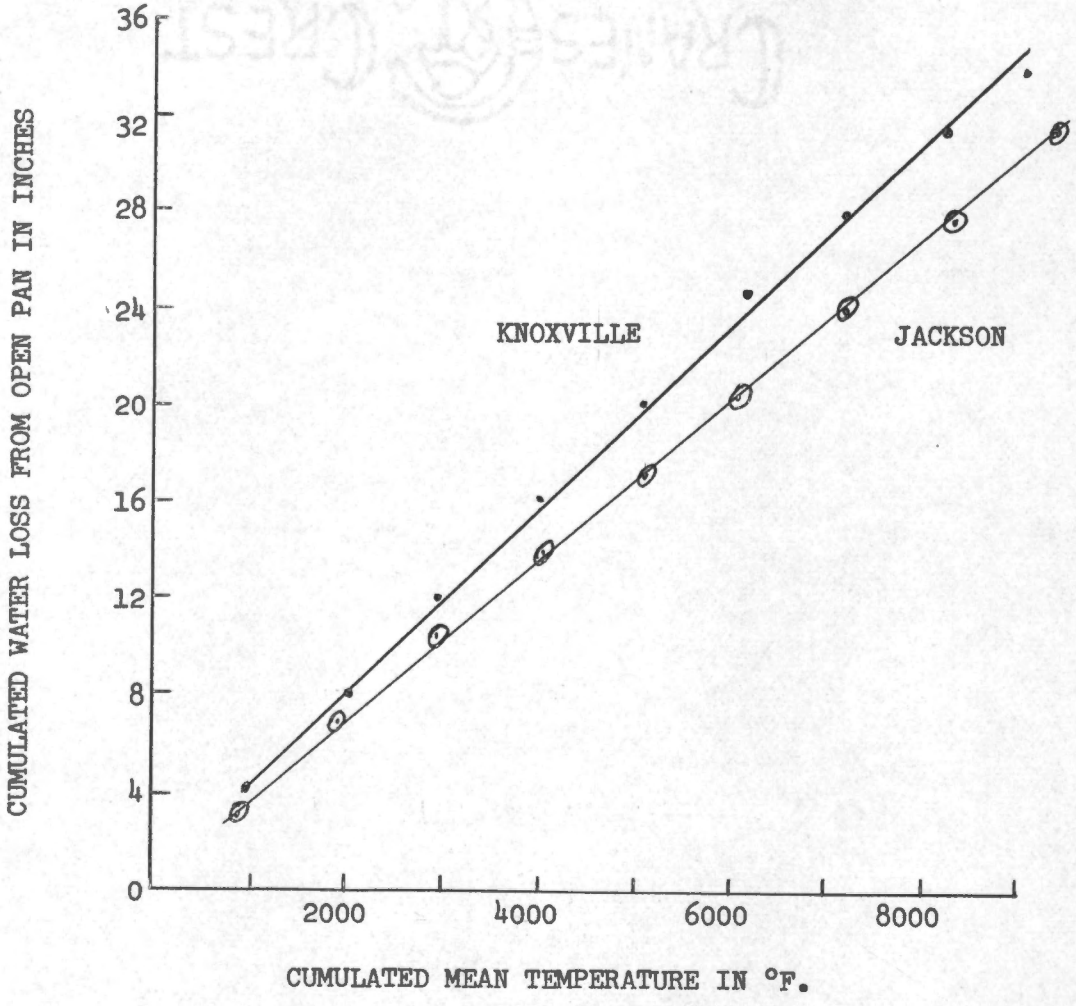


Figure 8. Relationship between mean temperature and water loss from open pan at Knoxville and Jackson.

The standard errors of estimate were quite low at both locations (0.1816 and 0.1214, respectively) (Tables II and III).

The correlation coefficient resulting from the correlation of cumulated water loss from open pan with cumulated wind speed at Knoxville was 0.9071 but the standard error of estimate was quite high (0.5439) (Table II). The corresponding correlation coefficient at Jackson was considerably lower (0.7619) and the standard error of estimate still higher (0.7299) (Table III). When multiple regressions were calculated with cumulated relative humidity, wind speed, and degree-sunshine hours the correlation coefficients were increased to 0.9979 and 0.9997 for Knoxville and Jackson, respectively. However, the standard error of estimate was quite high at Knoxville (0.8325) (Tables II and III).

VII. SOIL MOISTURE DEPLETION

The difference in the per cent moisture of the soil at the beginning of the growing season and at the end of the season is considered to be the "moisture depletion" by the crop. Soil moisture depletion plus any additions to soil moisture, either as rainfall or as irrigation water, is considered to be the total amount of water used by the crop.

Figures 9 through 14 show the per cent moisture by volume of the soil, measured in six-inch increments to a depth of 54 inches for a date early in the growing season and for a date after maturity of the corn crop under specified conditions.

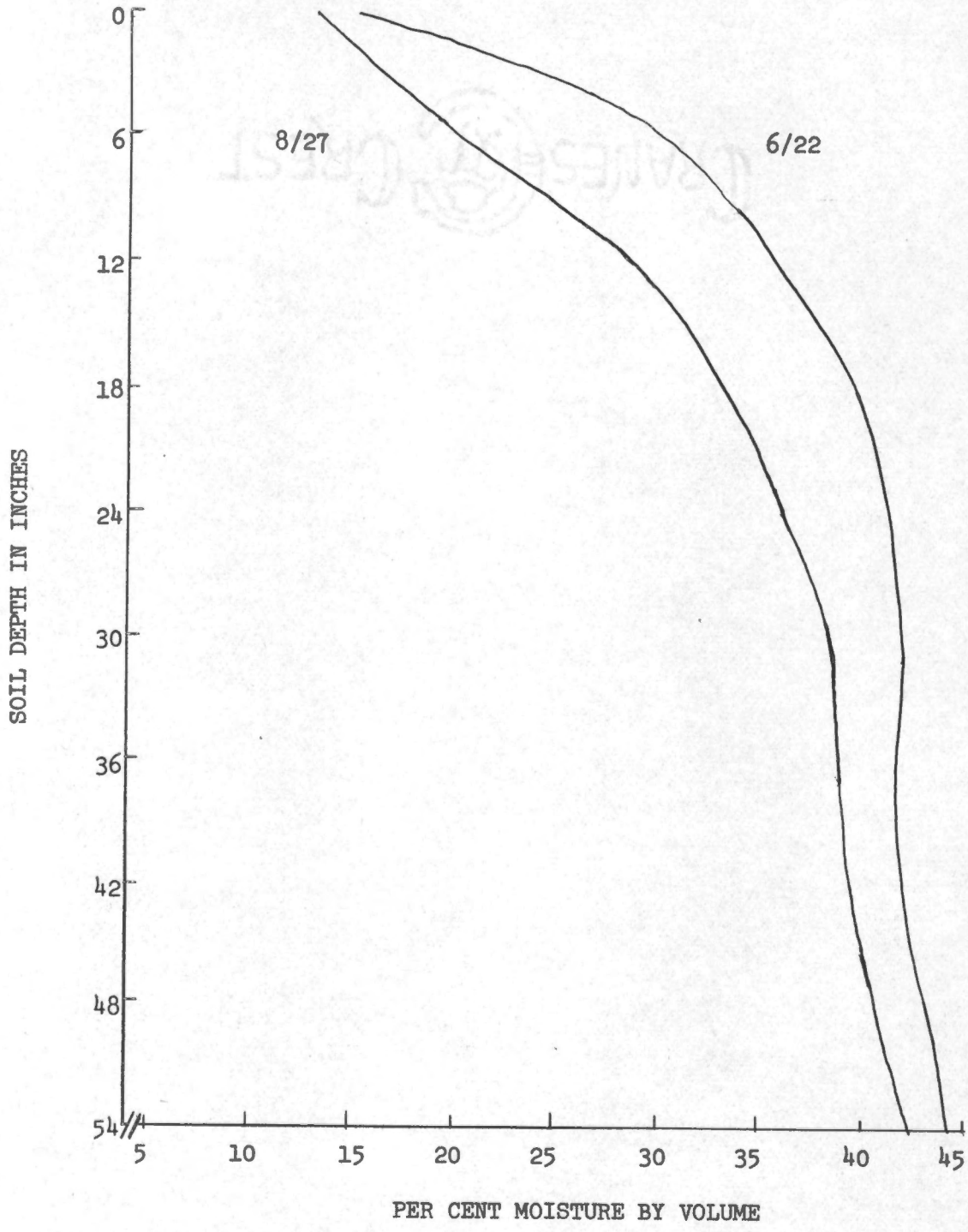


Figure 9. Net soil moisture depletion in 1962 for corn on a Sequatchie soil when unirrigated and receiving 120 lb. N/A.

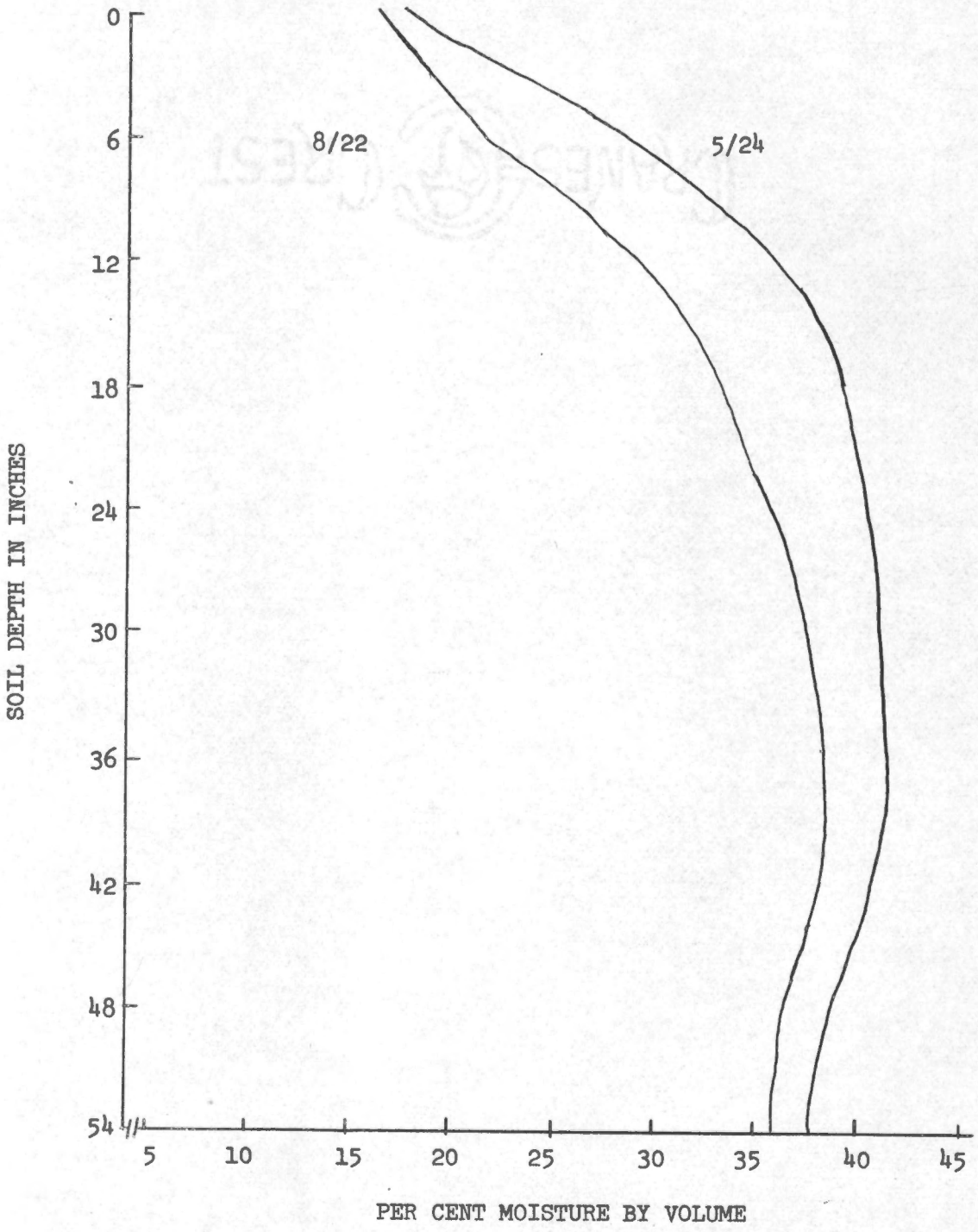


Figure 10. Net soil moisture depletion in 1963 for corn on a Sequatchie soil when unirrigated and receiving 120 lb. N/A.

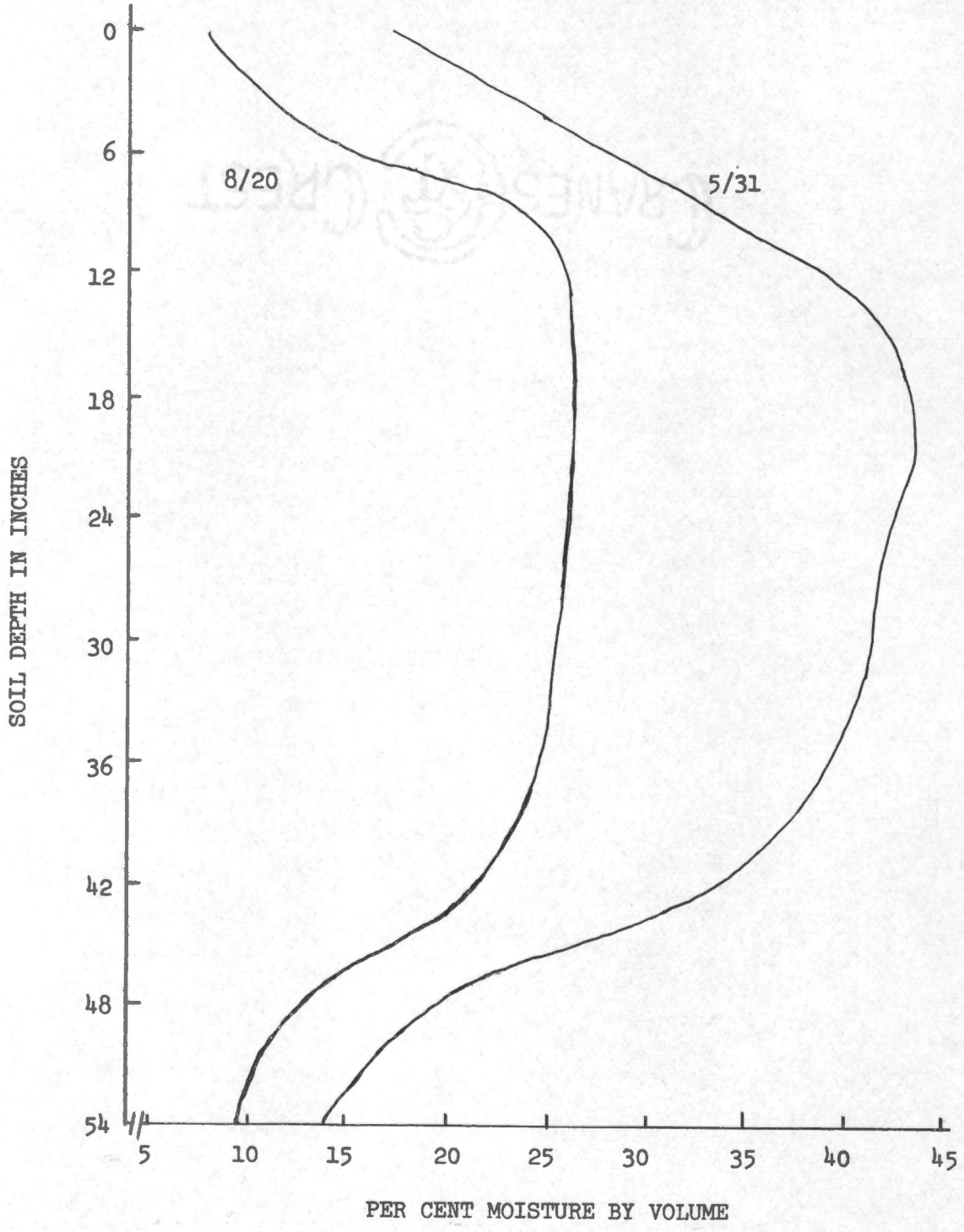


Figure 11. Net soil moisture depletion in 1962 for corn on a Memphis soil when unirrigated and receiving 120 lb. N/A.

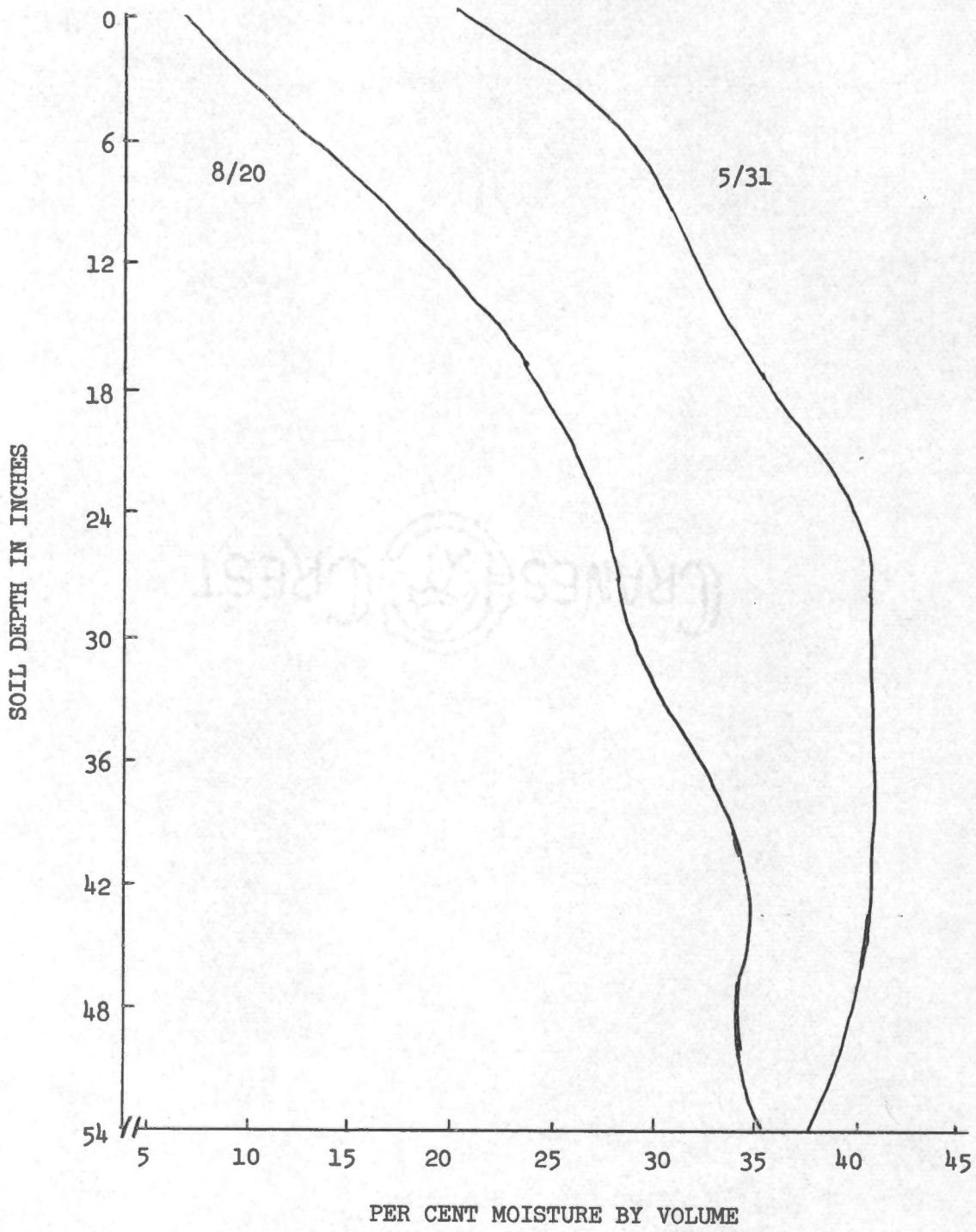


Figure 12. Net soil moisture depletion in 1962 for corn on a Memphis soil when irrigated at 2 atmospheres tension and receiving 120 lb. N/A.

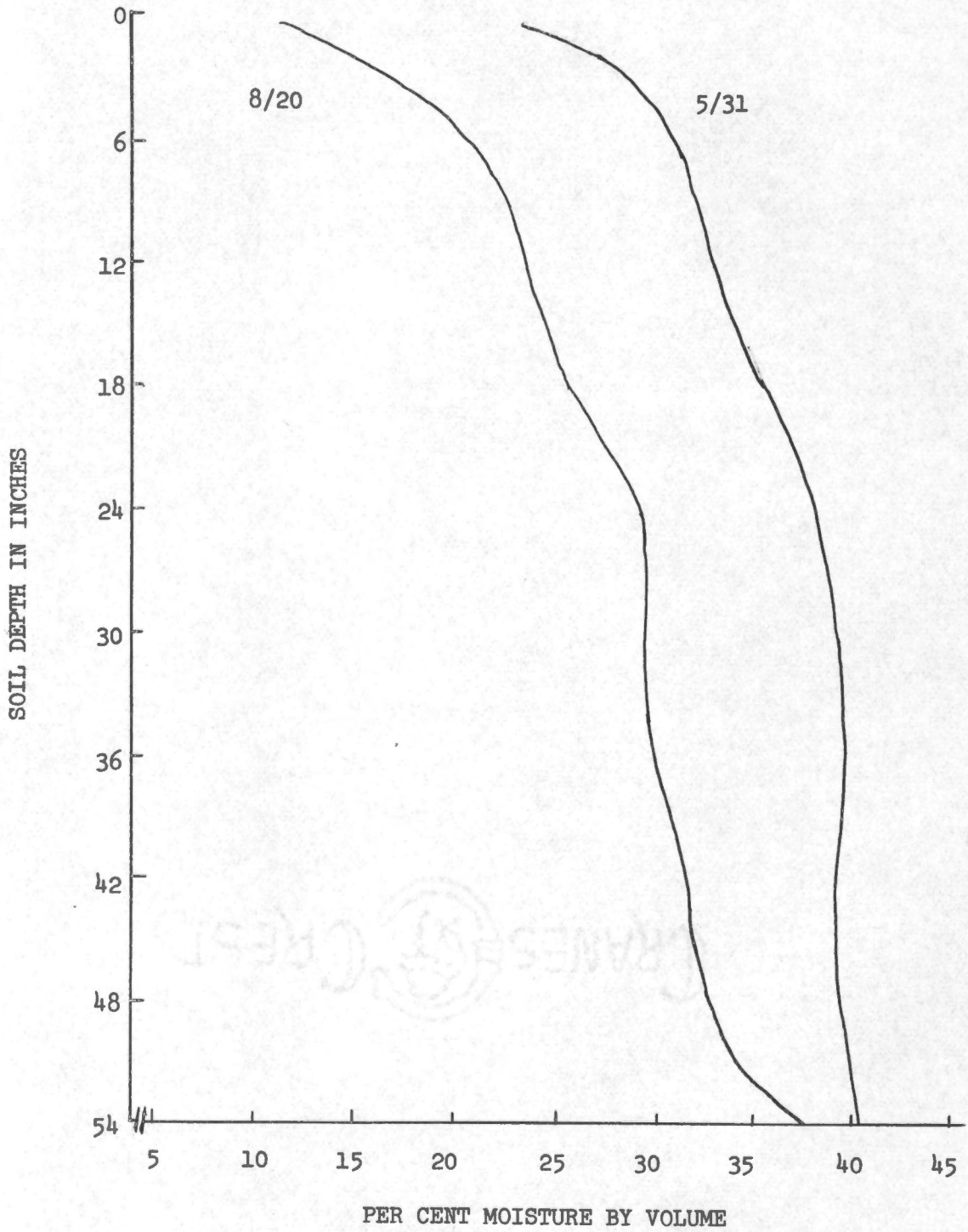


Figure 13. Net soil moisture depletion in 1962 for corn on a Memphis soil when irrigated at 2 atmospheres tension and receiving no nitrogen.

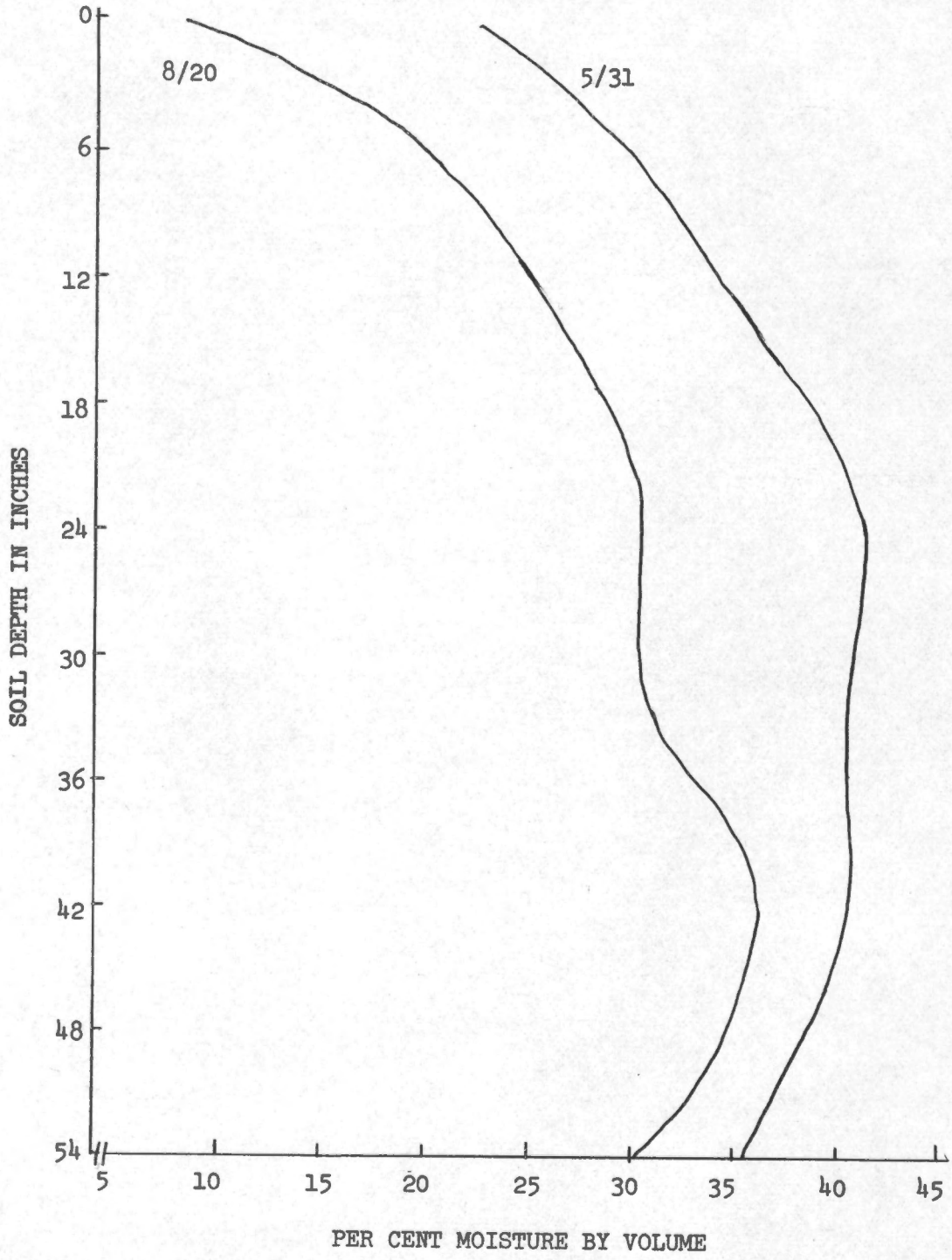


Figure 14. Net soil moisture depletion in 1962 for corn on a Memphis soil when irrigated at 2 atmospheres tension and receiving 300 lb. N/A.

At Knoxville in both years the per cent moisture near the surface was about the same at both dates. Further down the soil profile, however, it can be observed that the moisture content was considerably less at the end of the season. The area of greatest depletion appeared to be between the 6-inch and 30-inch depths (Figures 9 and 10).

The moisture content was less near the surface at both dates. The moisture content increased up to the 12 to 18-inch depth and remained relatively constant throughout the remaining profile that was sampled.

This is as could be expected since near the surface of the soil, moisture is being removed by both evaporation and transpiration. As depth is increased, evaporation becomes less important and at 12 to 18 inches is probably insignificant. At this point, transpiration alone is probably responsible for the depletion of moisture from the soil, assuming, as we have, that percolation is insignificant also.

There appeared to be no difference in soil moisture depletion between the two years (Figures 9 and 10).

The data from Jackson, although more erratic, point toward the same conclusions as that from Knoxville. The moisture content near the surface was considerably lower at the end of the season than at planting time.

The area of maximum depletion as well as the maximum moisture content occurred between 12 and 42 inches (Figure 11) when no irrigation water was applied. Under irrigated conditions, however, the area of moisture depletion decreased uniformly at greater depths (Figure 12).

This can probably best be explained by the larger concentration of roots one would expect to find at greater depths when no irrigation water was applied and a decreasing concentration of roots at greater depths under irrigated conditions.

Soil moisture depletion was much greater under unirrigated conditions as compared to irrigated conditions. This is true because the amount of water used by a corn crop often exceeds the amount of precipitation during the growing season and therefore the crop extracts moisture from the soil that has been stored there during the winter months.

Soil moisture depletion and per cent moisture declined sharply at about 36 to 42 inches depth at Jackson because of a sand layer at this depth (Figure 11).

The area of moisture depletion was relatively uniform throughout the soil profile that was sampled where no nitrogen was applied (Figure 13). However when nitrogen was applied, the area of depletion was larger between the 24 and 36 inch depths (Figure 14). This would indicate that the nitrogen resulted in a greater soil moisture depletion at this depth.

VIII. CORN YIELDS AS INFLUENCED BY NITROGEN LEVELS AND DROUTH INTENSITY

To evaluate yield as a function of nitrogen level and ET., rainfall and ET. data were used to estimate drouth intensity by the moisture balance method as described by Parks and Knetsch (40). They

found the 3.00-inch base to give the highest correlation, therefore this is the base that was used in this study.

Daily ET. was subtracted from this base and rainfall was added to it. When the base reached zero a drouth-day was considered to have occurred. In order to determine the relative importance of drouth occurring in different parts of the season, the relationship between drouth intensity, time that the drouth occurred, and corn yields was estimated. Parks and Knetsch (40) accomplished this by correlating the drouth conditions associated with corn yields. The results of their analysis are given by the equation:

$$\hat{Y} = 99.04 - 0.096A - 1.376B + 5.232C - 1.736D - 0.403C^2 - 0.146CB - 0.055CD + 0.042BD \quad (1)$$

where $\hat{Y}$ denotes the estimated yield in bushels per acre and the factors A through D denote the levels of drouth measured in number of drouth-days occurring in successive periods throughout the growing season of corn. It was assumed that corn would reach the tasseling stage after 65 days. This period is represented by terms A and B where A is the first 33 days and B the next 32 days after planting. The tasseling period of 14 days is given by the C term and the 31 days after tasseling is represented by term D.

A similar procedure was followed in this study to determine the influence of drouth intensity on corn yields. However, in this study the growing season was considered to be 126 days and was divided into nine 14-day periods. The results of this analysis are given by the

equation:

$$\hat{Y} = 147.255 - 3.758A - 1.084C - 2.077F - 2.419G - 1.214H - 0.563FE - 0.185FG + 0.280EG \quad (2)$$

where $\hat{Y}$ denotes the estimated yield in bushels per acre and the factors A through I denote the levels of drouth measured in number of drouth-days occurring in successive 14-day periods throughout the growing season of corn. The coefficients for terms B, D, E, I and F^2 were insignificant and therefore dropped from the equation. In this study it was assumed that the corn would reach the tasseling stage after 70 days. The tasseling period of 14 days would be represented by the F term.

The drouth index values derived from the above equations were considered together with different selected nitrogen treatments to derive a regression equation expressing the relationship between corn yield, nitrogen level, and drouth intensity. Three nitrogen levels were selected for this analysis, viz. no nitrogen, the recommended rate (120 lb.), and a high rate (300 lb.). In one analysis, the coefficients derived by Parks and Knetsch (40) were used with the above nitrogen levels and the drouth days derived in this study. The relationship is expressed as:

$$\hat{Y} = 68.8465 + 0.6691N - 0.0014N^2 - 0.1118D - 0.0029D^2 - 0.0016ND \quad (3)$$

where $\hat{Y}$ is the estimated yield in bushels per acre, N is pounds of nitrogen per acre, and D is the drouth index value as derived from equation (1). Equation (3) accounted for 86.4 per cent of the

variability of yield. The correlation was significant at the 0.10 level of probability.

In the other analysis, the coefficients derived from equation (2), where the growing season was divided into eight 14-day periods, were used with the same nitrogen levels and drouth days. The relationship is expressed as:

$$\hat{Y} = 69.5491 + 0.6821N - .0014N^2 - 0.1967D - 0.0054D^2 - 0.0010ND \quad (4)$$

where $\hat{Y}$ is the estimated yield in bushels per acre, N is pounds of nitrogen per acre, and D is the drouth index value as derived from equation (2). Equation (4) accounted for 88.6 per cent of the variability of yield and was significant at the 0.05 level of probability. Thus, the accuracy of the analysis was increased only 2 per cent by dividing the growing season into smaller periods.

A significant increase in yield was observed by irrigating at two atmospheres tension at Jackson in 1962. However, no significant response to irrigation was observed at Jackson in 1963 nor in Knoxville in 1962. A highly significant increase in yield was obtained by applying up to 120 pounds of nitrogen per acre at Jackson in 1962 and at Knoxville in 1963 and by applying up to 180 pounds of nitrogen per acre at Knoxville in 1962 and at Jackson in 1963. A significant interaction between irrigation and nitrogen was observed at both locations in 1962 (Tables XXII and XXIII).

The major limitation of this study is that ET. was determined from soil moisture loss to a depth of 54 inches of the soil profile and the percolation of excess water deeper into the profile, if any,

and the water used by the crop from deeper layers, if any, were not taken into consideration. However, these items are not expected to cause any appreciable change in the ET. under the conditions of these experiments.

CHAPTER V

SUMMARY AND CONCLUSIONS

Irrigation studies have been conducted in two phases. The first was aimed at determining the levels of soil moisture needed to maintain satisfactory growth of various crops. The second part of the task has been the development of a suitable means for determining when the soil moisture has been reduced to the point where irrigation should be applied. This is the phase of the problem with which we will be concerned in this report.

The tension at which soil moisture is held determines its availability to plants. In characterizing soil moisture availability the average tension must be used, recognizing at the same time that widely different stress values exist simultaneously in the root zone. It would seem advantageous, therefore, to employ a method in which the root zone is examined as whole, such as the ET. method.

Determining the ET. requirements of crops is an important problem in irrigated farming for scheduling the irrigations for optimum crop growth and determining the total water needs for an area. The climatological approach towards estimation of ET. appears to be comparatively simple and of more practical utility for guidance of the farmers than the other methods discussed. Under this approach, the main aim is to establish suitable relationships between ET. and one or more of the climatic factors believed to have a major effect on

consumptive use. The work done in this field by eminent workers was reviewed and their concepts and formulae were presented.

This was the second year of a pioneering study undertaken under Tennessee conditions to investigate the relationships between the climatic variables and ET. The results indicated that cumulated water loss from open pan was correlated with cumulated ET. under all treatments at the 0.05 level of probability. Since no significant difference was found between the correlations with different treatments, the average ET. of all treatments was used in the remaining calculations.

The correlations of "B-W" with both ET. and open pan were found to be highly significant. The standard errors of estimate were lower for ET. predicted from "B-W" than when predicted from water loss from open pan. This clearly indicates that atmometer bulbs could easily substitute for the open pan, if properly used, insofar as their applicability for predicting ET. under field conditions is concerned. Atmometers have an additional advantage over the open pan in that they are simple and can be used by anyone who is not located near a weather station.

Cumulated ET. and cumulated water loss from open pan were also found to be highly correlated with cumulated temperatures. Since the resulting standard errors of estimate were also low, these temperatures appear to be the easiest available records for the prediction of ET. with reasonable accuracy under field conditions in Tennessee.

On the basis of the results obtained, it would appear that the

use of atmometer bulbs or mean temperature is an effective means of predicting ET. Since both the atmometer bulbs and the maximum and minimum thermometers are easy to use and relatively inexpensive, they could prove to be of great value in scheduling irrigations. However, additional data would be desirable to support the present findings.

To make use of these correlations under field conditions, it is desirable to know the available moisture capacity of the soil in the rooting zone of a particular crop and the optimum level of moisture at which to irrigate this crop. The former information he can obtain by sampling and determining moisture content by the gravimetric method. The latter data is available in numerous publications for many crops (5, 7, 19). By multiplying the observed climatological data with appropriate coefficients of the regression equation, the ET. could be predicted for particular periods. The amount of available moisture present in the soil at the beginning of the period, the additions due to rains or irrigations and the deduction of the predicted ET. from the same, would indicate at a given time the amount of moisture remaining in the rooting zone of the crop. When the moisture is depleted to a predetermined level, depending upon the soil and crop, an irrigation should be applied. This would be a simple and easy way to regulate the irrigations for optimum crop growth.

Soil moisture depletion was much greater under unirrigated conditions than under irrigated conditions, as was expected. The area of maximum depletion occurred between 12 and 42 inches when no irrigation water was applied. Under irrigated conditions, however, the

amount of depletion decreased uniformly at greater depths.

The amount of moisture depletion was relatively uniform throughout the soil profile that was sampled where no nitrogen was applied. However, when nitrogen was applied, the amount of depletion was larger between the 24 and 36 inch depth, indicating that the nitrogen had leached to this depth resulting in a greater concentration of roots.

Drouth conditions for Knoxville and Jackson in 1962 and 1963 were indexed as to severity in accordance with the moisture deficiencies occurring at different stages of growth. The estimates of drouth intensity were made from climatological data. The drouth conditions were indexed using two methods. First, the season was divided into four unequal periods of 33, 32, 14 and 31 days each as described by Parks and Knetsch (40). Secondly, the season was divided into nine 14-day periods.

Corn yields were related to nitrogen level and drouth index, as calculated by both methods, by least square regression methods. The results indicate that the resultant equations accounted for 86.4 per cent and 88.6 per cent of the variability of yield, using four periods and nine periods, respectively. The correlations were significant at the 0.10 level of probability using the first method and at the 0.05 level using the second method. This would indicate that dividing the season into smaller periods was of little value in the prediction of yield.

The results indicate that a significant increase in corn yields can be obtained by using up to 120 pounds of nitrogen per acre.

Although no significant increase in yield was obtained by irrigating at Knoxville and a significant increase by irrigating at two atmospheres tension at Jackson only in 1962, the results are not conclusive since both years that this experiment was conducted were wetter than normal.

LITERATURE CITED

LITERATURE CITED

1. Bennett, O. L. and Doss, B. D. Effect of soil moisture on root distribution and cool-season forage species. Agron. Jour. 52:204-207. 1960.

2. Blaney, H. F. Climate as an index of irrigation needs. U.S.D.A. Yearbook of Agriculture, pp. 341-345. 1955.

3. _____. Irrigation requirements of crops. Agr. Engr. 32:665-668. 1951.

4. _____ and Criddle, W. D. Determining the consumptive use and irrigation water requirements. U.S.D.A. Agr. Res. Service Tech. Bul. 1275. 1952.

5. _____ and _____. Determining water requirements in irrigated areas from climatological and irrigation data. U.S.D.A. Soil Cons. Serv. SCS-TP-96. 48 pp. 1950.

6. Briggs, L. J. and Shantz, H. L. Daily transpiration during the normal growth period and its correlation with the weather. Jour. Agr. Sci. 7:155-212. 1916.

7. _____ and _____. Relative water requirements of plants. Jour. Agr. Sci. 3:1-64. 1914.

8. Carlson, C. W., Allessi, J. and Mickelson, R. H. Evapotranspiration and yield of corn as influenced by moisture level, nitrogen fertilization and plant density. Soil Sci. Soc. Amer. Proc. 23:242-245. 1959.

9. Criddle, W. D. Methods of computing consumptive use of water. Jour. of the Irrigation and Drainage Div. Amer. Soc. of Civil Engr. Proc. 84 (1):1-27. 1958.

10. Crowther, F. The effects of different combinations of nitrogen applications and water-supply. Ann. of Bot. 48:877-913. 1934.

11. Denmead, O. T. and Shaw, R. H. Evapotranspiration in relation to the development of the corn crop. Agron. Jour. 51:725-726. 1959.

12. _____ and _____. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. Jour. 52:272-274. 1960.

13. Doss, B. D., Bennet, O. L., and Ashley, D. A. Evapotranspiration by irrigated corn. Agron. Jour. 54:497-498. 1962.

14. Drinkwater, W. O. and Janes, B. E. Relation of potential evapotranspiration to environment and kind of plant. Amer. Geophys. Union Trans. 38:524-528. 1957.

15. Fritchen, L. J. and Van Bavel, C. H. M. Energy balance as affected by height and maturity of Sudangrass. Agron. Jour. 56:201-204. 1964.

16. Gardner, W. and Kirkham, D. Determination of soil moisture by neutron scattering. Soil Sci. 73:391-400. 1952.

17. Gingrich, J. R. and Russell, M. B. Effect of soil moisture tension and oxygen concentration on the growth of corn roots. Agron. Jour. 48:517. 1956.

18. Hagan, R. H., Peterson, M. L., Upchurch, R. P. and Jones, L. G. Relationships of soil moisture stress to different aspects of growth in Ladino clover. Soil Sci. Soc. Amer. Proc. 21:360-365. 1957.

19. Halkias, N. A., Veihmeyer, F. J. and Hendrickson, A. H. Determining water needs for crops from climatic data. Hilgardia 24:207-231. 1955.

20. Hanks, R. J. and Tanner, C. B. Water consumption by plants as influenced by soil fertility. Agron. Jour. 44:98-100. 1952.

21. Harrold, L. L., Peters, D. B., Dreibelbis, F. R., and McGuinness, J. L. Transpiration evaluation of corn grown on a plastic-covered lysimeter. Soil Sci. Soc. Amer. Proc. 23:174-178. 1959.

22. Haynes, J. L. The effect of availability of soil moisture upon vegetative growth and water use in corn. Jour. Amer. Soc. of Agron. 40:385-395. 1948.

23. Holt, R. F. and Van Doren, C. A. Water utilization by field corn in western Minnesota. Agron. Jour. 53:43-45. 1961.

24. Howe, O. W. and Rhodes, H. F. Irrigation practices for corn production in relation to stage of plant development. Soil Sci. Soc. Amer. Proc. 19:94-98. 1955.

25. Jamison, V. C. and Beale, O. W. Irrigation of corn in eastern United States. U.S.D.A. Agr. Handbook No. 140. 13 pp. 1958.

26. Janes, B. E. Estimation of potential evapotranspiration from vegetable crops from net solar radiation. Proc. Amer. Soc. of Hort. Sci. 76:582-589. 1960.

27. _____. Predicting need for irrigation by measuring loss of water from atmometers. Connecticut Agr. Exp. Sta. Prog. Rept. No. 42. 6 pp. 1960.

28. Kiesselbach, T. A. and Montgomery, E. G. The relation of climatic factors to the water use by corn plants. Nebraska Agr. Exp. Sta. 24th. Ann. Rept., pp. 91-107. 1911.

29. Koehler, F. E., Guettinger, D. L. and Nelson, W. L. Nitrogen and moisture utilization by wheat I: Low rainfall areas. Agron. Abs. Pan Amer. Agron. Annual Meetings, Amer. Soc. of Agron., p. 41. 1963.

30. Krantz, B. A. and Chandler, W. V. Fertilize corn for higher yields. North Carolina Agr. Exp. Sta. Bul. 366 (Revised). 70 pp. 1954.

31. Kulkarni, K. R. Effect of some climatic factors on evapotranspiration in corn. Unpublished Master's thesis. The University of Tennessee, Knoxville. 127 pp. 1963.

32. Kuranz, J. L. Measurement of moisture and density in soils by the nuclear method. Nuclear-Chicago Corporation, 333 East Howard Ave., Des Plaines, Illinois. (Mimeographed). 11 pp.

33. Letey, J. and Peters, D. B. Influence of soil moisture levels and seasonal weather on efficiency of water use by corn. Agron. Jour. 49:362-365. 1957.

34. Livingston, B. E. Atmometers of porous porcelain and paper, their use in physiological ecology. Ecology. 16:438-472. 1935.

35. Lowry, R. L. and Johnson, A. F. Consumptive use of water for agriculture. Amer. Soc. of Civil Engr. Trans. 107:1243-1302. 1942.

36. Marvin, C. F. Psychometric tables for obtaining the vapor pressure, relative humidity, and temperature of the dew point from readings of the wet-and dry-bulb thermometers. U. S. Dept. of Commerce. Weather Bureau Bul. No. 235. 87 pp. 1941.

37. McWhorter, J. C. and Bruce, R. R. The relation of solar radiation to measured evapotranspiration. Mississippi Agr. Exp. Sta. Publ. 1060. 7 pp. 1963.

38. Miller, M. F. and Duley, F. L. The effect of a varying moisture supply upon the development and composition of the maize plant at different periods of growth. Missouri Agr. Exp. Sta. Res. Bul. 76. 36 pp. 1925.

39. Munson, W. C. Method for estimating consumptive use of water for agriculture. Jour. of the Irrigation and Drainage Div. Amer. Soc. of Civil Engr. Proc. 86 (6):45-57. 1960.

40. Parks, W. L. and Knetsch, J. L. Corn yields as influenced by nitrogen levels and drouth intensity. Agron. Jour. 51:363-364. 1959.

41. _____ and Lillard, J. H. Efficient utilization of water by crops. Assn. of Sou. Agr. Workers, Inc. Proc., pp. 59-60. 1963.

42. Pelton, W. L., King, K. M. and Tanner, C. B. An evaluation of Thornthwaite and mean and temperature methods of determining potential evapotranspiration. Agron. Jour. 387-395. 1960.

43. Penman, H. L. Estimating evaporation. Amer. Geophys. Union Trans. 37:43-50. 1956.

44. _____. Natural evaporation from open water, bare soil and grass. Roy. Soc. of London Proc. Series A. 193:120-145. 1948.

45. Peters, D. B. Water uptake of corn roots as influenced by soil moisture content and soil moisture tension. Soil Sci. Soc. Amer. Proc. 21:481-484. 1957.

46. _____ and Russell, M. B. Relative water losses by evaporation and transpiration in field corn. Soil Sci. Soc. Amer. Proc. 23:170-173. 1959.

47. Richards, L. A. and Richards, S. J. Soil moisture. U.S.D.A. Yearbook of Agriculture, pp. 49-60. 1957.

48. Rhoades, H. F. and Nelson, L. B. Growing 100-bushel corn with irrigation. U.S.D.A. Yearbook of Agriculture, pp. 394-400. 1955.

49. Robins, J. S. and Domingo, C. E. Some effects of severe soil moisture deficits at specific growth stages of corn. Agron. Jour. 45:618-621.

50. Russell, M. B. and Danielson, R. E. Time and depth patterns of water use by corn. Agron. Jour. 48:163-165. 1956.

51. Smith, L. E. and Thomas, D. W. Water, nitrogen, and seeding rate relationships. Purdue Univ. Agr. Exp. Sta. Res. Bul. 755. 24 pp. 1962.

52. Stolzy, L. H. and Cahoon, G. A. A field-calibrated portable neutron rate meter for measuring soil moisture in citrus orchards. Soil Sci. Soc. Amer. Proc. 21:571-575. 1957.

53. Stone, J. F., Kirkham, D. and Read, A. A. Soil moisture determination by a portable neutron-scattering moisture meter. Soil Sci. Soc. Amer. Proc. 19:419-423. 1955.

54. Tanner, C. B. and Lemon, E. R. Radiant energy utilized in evapotranspiration. Agron. Jour. 54:207-212. 1962.

55. Taylor, S. A. Use of mean soil moisture tension to evaluate the effect of soil moisture on crop yields. Soil Sci. 74:217-226. 1952.

56. _____. Use of moisture by plants. U.S.D.A. Yearbook of Agriculture, pp. 61-66. 1957.

57. _____ and Haddock, J. L. Soil moisture availability related to power required to remove water. Soil Sci. Soc. Amer. Proc. 20:284-288. 1956.

58. _____ and Slater, C. S. When to irrigate and how much water to apply. U.S.D.A. Yearbook of Agriculture, pp. 372-376. 1955.

59. Thornthwaite, C. W. An approach toward a rational classification of climate. Geograph. Rev. 38:55-94. 1948.

60. _____ and Mather, J. R. The water budget and its use in irrigation. U.S.D.A. Yearbook of Agriculture, pp. 346-357. 1955.

61. Van Bavel, C. H. M. Agricultural drought in North Carolina. North Carolina Agr. Exp. Sta. Tech. Bul. No. 122. 60 pp. 1956.

62. _____. Estimating soil moisture conditions and time for irrigating with the evapotranspiration method. U.S.D.A. ARS 41-11. 16 pp. 1957.

63. Vazquez, Roberto and Taylor, S. A. Simulated root distribution and water removal rates from moist soil. Soil Sci. Soc. Amer. Proc. 22:106-110. 1958.

64. Veihmeyer, F. J. and Hendrickson, A. H. Does transpiration decrease as the soil moisture decreases? Amer. Geophys. Union Trans. 36:425-448. 1955.

65. _____ and _____. Rates of evaporation from wet and dry soils and their significance. Soil Sci. 80:61-67. 1955.

66. Wadleigh, C. H. Soil moisture in relation to plant growth. U.S.D.A. Yearbook of Agriculture, pp. 358-361. 1955.

67. Weaver, H. A. and Pearson, R. W. Influence of nitrogen fertilization and plant population density on evapotranspiration by sudan grass. Soil Sci. 81:443-451. 1956.

68. World Almanac and Book of Facts. New York World-Telegram and The Sun. New York. 1963.

APPENDIX

TABLE IV

MEASURED EVAPOTRANSPIRATION IN CORN FOR SOME TREATMENTS ON A SEQUATCHIE SOIL AT KNOXVILLE DURING 1962

Period no.	Period[a]		No. of days	Evapotranspiration in acre inches									
				No irrigation[b]		2 atmospheres[b]		No nitrogen[c]		120 lb. nitrogen[c]		Average of all treatments	
	From	To		Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total
1	5/10	5/23	14	0.14	1.9	0.14	1.9	0.14	1.9	0.14	1.9	0.14	1.9
2	5/24	6/6	14	0.16	4.1	0.16	4.1	0.16	4.1	0.16	4.1	0.16	4.1
3	6/7	6/20	14	0.16	6.3	0.16	6.3	0.16	6.3	0.16	6.3	0.16	6.3
4	6/21	7/4	14	0.16	8.5	0.17	8.6	0.15	8.4	0.18	8.8	0.16	8.6
5	7/5	7/18	14	0.16	10.7	0.19	11.3	0.18	10.9	0.19	11.5	0.18	11.1
6	7/19	8/1	14	0.09	11.9	0.16	13.6	0.12	12.6	0.13	13.4	0.14	13.0
7	8/2	8/15	14	0.17	14.3	0.31	17.8	0.28	16.5	0.27	17.1	0.28	16.9
8	8/16	8/29	14	0.14	16.3	0.13	19.7	0.15	18.6	0.14	19.1	0.15	18.9
9	8/30	9/12	14	0.14	18.3	0.14	21.6	0.14	20.5	0.14	21.0	0.14	20.9
Total	5/10	9/12	126		18.3		21.6		20.5		21.0		20.9

[a]Each period includes 2 measurements but dates were adjusted slightly to give equal number of days.

[b]Averaged across all nitrogen levels.

[c]Averaged across all moisture levels.

TABLE V

MEASURED EVAPOTRANSPIRATION IN CORN FOR SOME TREATMENTS ON A SEQUATCHIE SOIL AT KNOXVILLE DURING 1963

Period no.	Period[a]		No. of days	Evapotranspiration in acre inches									
				No irrigation[b]		2 atmospheres[b]		No nitrogen[c]		120 lb. nitrogen[c]		Average of all treatments	
	From	To		Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total
1	4/20	5/3	14	0.11	1.3	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5
2	5/4	5/17	14	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4
3	5/18	5/31	14	0.23	6.6	0.23	6.6	0.21	6.4	0.23	6.6	0.22	6.5
4	6/1	6/14	14	0.12	8.2	0.12	8.3	0.12	8.2	0.13	8.4	0.13	8.3
5	6/15	6/28	14	0.18	10.7	0.19	11.0	0.18	10.7	0.21	11.4	0.19	11.0
6	6/29	7/12	14	0.18	13.3	0.18	13.6	0.19	13.4	0.20	14.1	0.19	13.6
7	7/13	7/26	14	0.16	15.6	0.17	15.9	0.14	15.4	0.18	16.6	0.17	16.0
8	7/27	8/9	14	0.21	18.5	0.20	18.7	0.20	18.2	0.21	19.6	0.20	18.8
9	8/10	8/23	14	0.11	20.1	0.13	20.6	0.11	19.8	0.12	21.3	0.12	20.5
Total	4/20	8/23	126		20.1		20.6		19.8		21.3		20.5

[a]Each period includes 2 measurements but dates were adjusted slightly to give equal number of days.

[b]Averaged across all nitrogen levels.

[c]Averaged across all moisture levels.

TABLE VI

MEASURED EVAPOTRANSPIRATION IN CORN FOR SOME TREATMENTS ON A MEMPHIS SOIL AT JACKSON DURING 1962

Period no.	Period[a]		No. of days	Evapotranspiration in acre inches									
				No irrigation[b]		2 atmospheres[b]		No nitrogen[c]		120 lb. nitrogen[c]		Average of all treatments	
	From	To		Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total
1	4/20	5/3	14	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5
2	5/4	5/17	14	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4
3	5/18	5/31	14	0.17	5.8	0.17	5.8	0.17	5.8	0.17	5.8	0.17	5.8
4	6/1	6/14	14	0.19	8.4	0.20	8.5	0.18	8.4	0.18	8.4	0.19	8.4
5	6/15	6/28	14	0.16	10.6	0.23	11.8	0.18	10.9	0.19	11.0	0.18	11.0
6	6/29	7/12	14	0.21	13.6	0.27	15.5	0.24	14.3	0.26	14.6	0.26	14.6
7	7/13	7/26	14	0.19	16.2	0.26	19.2	0.16	16.6	0.18	17.1	0.17	17.0
8	7/27	8/9	14	0.10	17.6	0.23	22.4	0.22	19.6	0.22	20.1	0.22	20.1
9	8/10	8/23	14	0.05	18.3	0.11	24.0	0.09	20.9	0.08	21.3	0.09	21.3
Total	4/20	8/23	126		18.3		24.0		20.9		21.3		21.3

[a]Each period includes 2 measurements but dates were adjusted slightly to give equal number of days.

[b]Averaged across all nitrogen levels.

[c]Averaged across all moisture levels.

TABLE VII

MEASURED EVAPOTRANSPIRATION IN CORN FOR SOME TREATMENTS ON A MEMPHIS SOIL AT JACKSON DURING 1963

Period no.	Period[a]		No. of days	Evapotranspiration in acre inches									
				No irrigation[b]		2 atmospheres[b]		No nitrogen[c]		120 lb. nitrogen[c]		Average of all treatments	
	From	To		Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total
1	4/20	5/3	14	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5
2	5/4	5/17	14	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4
3	5/18	5/31	14	0.13	5.2	0.20	6.2	0.15	5.5	0.14	5.3	0.14	5.4
4	6/1	6/14	14	0.20	7.9	0.30	10.5	0.23	8.8	0.20	8.2	0.22	8.5
5	6/15	6/28	14	0.16	10.1	0.13	12.3	0.13	10.6	0.15	10.3	0.14	10.5
6	6/29	7/12	14	0.24	13.4	0.22	15.4	0.20	13.4	0.23	13.5	0.22	13.6
7	7/13	7/26	14	0.20	16.2	0.22	18.5	0.21	16.3	0.22	16.6	0.23	16.8
8	7/27	8/9	14	0.14	18.1	0.17	20.9	0.15	18.4	0.16	18.8	0.17	19.1
9	8/10	8/23	14	0.10	19.4	0.12	22.6	0.12	20.0	0.11	20.3	0.11	20.7
Total	4/20	8/23	126		19.4		22.6		20.0		20.3		20.7

[a]Each period includes 2 measurements but dates were adjusted slightly to give equal number of days.

[b]Averaged across all nitrogen levels.

[c]Averaged across all moisture levels.

TABLE VIII

MEASURED EVAPOTRANSPIRATION IN CORN UNDER DIFFERENT MOISTURE AND NITROGEN LEVELS ON A SEQUATCHIE SOIL AT KNOXVILLE DURING 1962

Period no.	Period		No. of days	Evapotranspiration in acre inches																	
				No irrigation						5 Atmospheres tension						2 Atmospheres tension					
				No nitrogen		120 lb. N/A		300 lb. N/A		No nitrogen		120 lb. N/A		300 lb. N/A		No nitrogen		120 lb. N/A		300 lb. N/A	
	From	To		Mean/ Day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total
1	5/10	5/23	14	0.14	1.9	0.14	1.9	0.14	1.9	0.14	1.9	0.14	1.9	0.14	1.9	0.14	1.9	0.14	1.9	0.14	1.9
2	5/24	6/6	14	0.16	4.1	0.16	4.1	0.16	4.1	0.16	4.1	0.16	4.1	0.16	4.1	0.16	4.1	0.16	4.1	0.16	4.1
3	6/7	6/20	14	0.16	6.3	0.16	6.3	0.16	6.3	0.16	6.3	0.16	6.3	0.16	6.3	0.16	6.3	0.16	6.3	0.16	6.3
4	6/21	7/4	14	0.15	8.4	0.15	8.4	0.16	8.5	0.15	8.4	0.19	8.9	0.16	8.6	0.15	8.4	0.19	8.9	0.17	8.6
5	7/5	7/18	14	0.17	10.8	0.16	10.7	0.16	10.7	0.18	11.0	0.20	11.7	0.19	11.2	0.19	11.0	0.22	12.1	0.17	10.9
6	7/19	8/1	14	0.06	11.7	0.10	12.1	0.09	12.0	0.15	13.0	0.15	13.8	0.19	13.9	0.16	13.2	0.15	14.2	0.17	13.3
7	8/2	8/15	14	0.19	14.4	0.15	14.2	0.17	14.4	0.34	17.8	0.37	19.0	0.35	18.8	0.29	17.3	0.29	18.2	0.34	18.0
8	8/16	8/29	14	0.16	16.6	0.13	16.0	0.14	16.4	0.17	20.2	0.16	21.3	0.15	20.8	0.12	19.0	0.12	19.9	0.16	20.2
9	8/30	9/12	14	0.14	18.5	0.14	17.9	0.14	18.4	0.14	22.1	0.14	23.3	0.14	22.8	0.14	20.9	0.14	21.9	0.14	22.1
Total	5/10	9/12	126		18.5		17.9		18.4		22.1		23.3		22.8		20.9		21.9		22.1

TABLE IX

MEASURED EVAPOTRANSPIRATION IN CORN UNDER DIFFERENT MOISTURE AND NITROGEN LEVELS ON A SEQUATCHIE SOIL AT KNOXVILLE DURING 1963

Period no.	Period		No. of days	Evapotranspiration in acre inches																	
				No irrigation						5 Atmospheres tension						2 Atmospheres tension					
				No nitrogen		120 lb. N/A		300 lb. N/A		No nitrogen		120 lb. N/A		300 lb. N/A		No nitrogen		120 lb. N/A		300 lb. N/A	
	From	To		Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total
1	4/20	5/3	14	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5
2	5/4	5/17	14	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4
3	5/18	5/31	14	0.22	6.5	0.23	6.6	0.23	6.6	0.19	6.0	0.23	6.6	0.21	6.4	0.23	6.6	0.23	6.6	0.23	6.6
4	6/1	6/14	14	0.12	8.2	0.12	8.2	0.11	8.2	0.15	8.1	0.14	8.6	0.13	8.2	0.12	8.2	0.13	8.4	0.12	8.3
5	6/15	6/28	14	0.14	10.2	0.20	11.1	0.19	10.9	0.20	10.9	0.22	11.7	0.19	10.9	0.19	10.9	0.21	11.3	0.18	10.8
6	6/29	7/12	14	0.15	12.3	0.20	13.9	0.20	13.7	0.23	14.1	0.21	14.6	0.19	13.5	0.20	13.7	0.18	13.9	0.17	13.1
7	7/13	7/26	14	0.15	14.4	0.15	16.1	0.19	16.3	0.16	16.3	0.18	17.1	0.19	16.1	0.13	15.5	0.21	16.7	0.17	15.5
8	7/27	8/9	14	0.21	17.3	0.22	19.1	0.21	19.1	0.20	19.2	0.20	19.9	0.20	18.9	0.19	18.2	0.22	19.8	0.19	18.2
9	8/10	8/23	14	0.10	18.7	0.12	20.8	0.12	20.8	0.12	20.9	0.12	21.6	0.12	20.5	0.12	19.8	0.12	21.5	0.16	20.4
Total	4/20	8/23	126		18.7		20.8		20.8		20.9		21.6		20.5		19.8		21.5		20.4

TABLE X

MEASURED EVAPOTRANSPIRATION IN CORN UNDER DIFFERENT MOISTURE AND NITROGEN LEVELS ON A MEMPHIS SOIL AT JACKSON DURING 1962

Period no.	Period		No. of days	Evapotranspiration in acre inches																	
				No irrigation						5 Atmospheres tension						2 Atmospheres tension					
				No nitrogen		120 lb. N/A		300 lb. N/A		No nitrogen		120 lb. N/A		300 lb. N/A		No nitrogen		120 lb. N/A		300 lb. N/A	
	From	To		Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total	Mean/ day	Cumulated total
1	4/20	5/3	14	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5
2	5/4	5/17	14	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4
3	5/18	5/31	14	0.17	5.8	0.17	5.8	0.17	5.8	0.17	5.8	0.17	5.8	0.17	5.8	0.17	5.8	0.17	5.8	0.17	5.8
4	6/1	6/14	14	0.18	8.3	0.19	8.5	0.20	8.5	0.18	8.3	0.17	8.2	0.18	8.3	0.19	8.5	0.19	8.5	0.21	8.7
5	6/15	6/28	14	0.15	10.4	0.17	10.8	0.16	10.8	0.16	10.5	0.15	10.2	0.17	10.7	0.24	11.9	0.25	11.9	0.21	11.7
6	6/29	7/12	14	0.20	13.1	0.22	13.9	0.21	13.7	0.28	14.3	0.28	14.1	0.32	15.1	0.25	15.4	0.27	15.8	0.27	15.5
7	7/13	7/26	14	0.19	15.7	0.20	16.8	0.17	16.2	0.06	15.1	0.06	14.9	0.11	16.6	0.25	18.8	0.27	19.5	0.26	19.1
8	7/27	8/9	14	0.09	16.9	0.09	18.1	0.11	17.7	0.34	19.9	0.32	19.4	0.32	21.1	0.22	21.9	0.24	22.9	0.24	22.5
9	8/10	8/23	14	0.06	17.8	0.04	18.6	0.05	18.4	0.09	21.2	0.09	20.7	0.10	22.6	0.12	23.6	0.12	24.5	0.10	23.9
Total	4/20	8/23	126		17.8		18.6		18.4		21.2		20.7		22.6		23.6		24.5		23.9

TABLE XI

MEASURED EVAPOTRANSPIRATION IN CORN UNDER DIFFERENT MOISTURE AND NITROGEN LEVELS ON A MEMPHIS SOIL AT JACKSON DURING 1963

Period no.	Period		No. of days	Evapotranspiration in acre inches																	
				No irrigation						5 Atmospheres tension						2 Atmospheres tension					
				No nitrogen		120 lb. N/A		300 lb. N/A		No nitrogen		120 lb. N/A		300 lb. N/A		No nitrogen		120 lb. N/A		300 lb. N/A	
	From	To		Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total	Mean/ day	Cumu- lated total
1	4/20	5/3	14	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5	0.11	1.5
2	5/4	5/17	14	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4	0.13	3.4
3	5/18	5/31	14	0.16	5.6	0.12	5.1	0.10	4.9	0.06	4.2	0.12	5.1	0.11	5.0	0.23	6.7	0.17	5.8	0.20	6.2
4	6/1	6/14	14	0.23	8.8	0.17	7.6	0.19	7.4	0.16	6.5	0.15	7.2	0.17	7.4	0.31	11.0	0.29	9.8	0.31	10.6
5	6/15	6/28	14	0.15	10.9	0.16	9.9	0.20	9.5	0.14	8.5	0.15	9.3	0.13	9.2	0.11	12.5	0.14	11.8	0.15	12.7
6	6/29	7/12	14	0.19	13.5	0.22	12.9	0.31	13.9	0.20	11.3	0.24	12.7	0.20	11.9	0.22	15.5	0.22	14.9	0.24	15.9
7	7/13	7/26	14	0.16	15.7	0.23	16.1	0.20	16.6	0.23	14.4	0.27	16.5	0.31	16.3	0.24	18.9	0.16	17.1	0.25	19.4
8	7/27	8/9	14	0.13	17.5	0.16	18.3	0.13	18.4	0.16	16.6	0.18	19.0	0.24	19.6	0.16	21.2	0.15	19.1	0.20	22.2
9	8/10	8/23	14	0.12	19.1	0.10	19.6	0.08	19.6	0.10	18.0	0.11	20.5	0.13	21.4	0.13	23.0	0.12	20.8	0.12	23.9
Total	4/20	8/23	126		19.1		19.6		19.6		18.0		20.5		21.4		23.0		20.8		23.9

TABLE XII

DROUTH-DAY OCCURRENCE USING FOUR PERIODS AT A 3.00 INCH MOISTURE BASE AT KNOXVILLE AND JACKSON DURING 1962 AND 1963

Period	Knoxville						Jackson					
	1962			1963[a]			1962			1963		
	No irrig.	5 Atm. ten.	2 Atm. ten.	No irrig.	5 Atm. ten.	2 Atm. ten.	No irrig.	5 Atm. ten.	2 Atm. ten.	No irrig.	5 Atm. ten.	2 Atm. ten.
A	7	7	7	0			4	4	4	0	0	0
B	1	1	1	0			18	18	5	3	3	1
C	7	0	0	0			10	6	0	8	8	0
D	8	0	0	4			23	0	0	19	10	3
Total	23	8	8	4			55	28	9	30	21	4

Knoxville 1962
A = 5/10 - 6/11
B = 6/12 - 7/13
C = 7/14 - 7/29
D = 7/28 - 8/27

110 days

Knoxville 1963 and Jackson 1962 and 1963
A = 4/20 - 5/22
B = 5/23 - 6/23
C = 6/24 - 7/7
D = 7/8 - 8/7

110 days

[a]No irrigation at Knoxville in 1963.

TABLE XIII

DROUTH-DAY OCCURRENCE USING NINE PERIODS AT A 3.00 INCH MOISTURE BASE AT KNOXVILLE AND JACKSON DURING 1962 AND 1963

Period	Knoxville						Jackson					
	1962			1963[a]			1962			1963		
	No irrig.	5 Atm. ten.	2 Atm. ten.	No irrig.	5 Atm. ten.	2 Atm. ten.	No irrig.	5 Atm. ten.	2 Atm. ten.	No irrig.	5 Atm. ten.	2 Atm. ten.
A	7	7	7	0			0	0	0	0	0	0
B	0	0	0	0			0	0	0	0	0	0
C	0	0	0	0			11	11	9	2	2	1
D	1	1	1	0			3	3	0	0	0	0
E	1	0	0	0			11	11	0	3	3	0
F	6	0	0	0			7	3	0	8	8	0
G	0	0	0	0			13	0	0	9	8	3
H	10	0	0	4			12	0	0	10	0	1
I	6	4	4	0			14	4	4	14	9	14
Total	31	12	12	4			71	32	13	46	30	19

Knoxville 1962

A = 5/10 - 5/23
B = 5/24 - 6/6
C = 6/7 - 6/20
D = 6/21 - 7/4
E = 7/5 - 7/18
F = 7/19 - 8/1
G = 8/2 - 8/15
H = 8/16 - 8/29
I = 8/30 - 9/12

126 days

Knoxville 1963 and Jackson 1962 and 1963

A = 4/20 - 5/3
B = 5/4 - 5/17
C = 5/18 - 5/31
D = 6/1 - 6/14
E = 6/15 - 6/28
F = 6/29 - 7/12
G = 7/13 - 7/26
H = 7/27 - 8/9
I = 8/10 - 8/23

126 days

[a]No irrigation at Knoxville in 1963.

TABLE XIV

TEMPERATURES AND RELATIVE HUMIDITY RECORDED AT THE AGRICULTURAL EXPERIMENT STATION AT KNOXVILLE DURING 1962

Period no.	Period		No. of days	Maximum temperature (°F.)		Minimum temperature (°F.)		Mean temperature (°F.)		Dew point temperature (°F.)		Relative humidity (per cent)		Degree-sunshine hours	
	From	To		Mean/day	Cumulated total	Mean/day	Cumulated total	Mean/day	Cumulated total	Mean/day	Cumulated total	Mean/day	Cumulated total	Mean/day	Cumulated total
1	5/10	5/23	14	91.5	1281	66.4	929	78.9	1105.0	48.3	676	91.4	1280	1106.8	15,496
2	5/24	6/6	14	89.9	2540	65.5	1846	77.7	2193.0	47.0	1340	87.7	2508	1101.7	30,919
3	6/7	6/20	14	85.5	3737	61.9	2712	73.7	3224.5	44.9	1969	88.9	3752	1066.8	45,855
4	6/21	7/4	14	87.6	4964	67.4	3655	77.5	4309.5	41.6	2552	87.9	4983	1123.7	61,586
5	7/5	7/18	14	89.6	6218	67.1	4594	78.3	5406.0	44.2	3171	83.4	6151	1124.3	77,327
6	7/19	8/1	14	87.4	7442	62.7	5472	75.1	6457.0	68.6	4132	81.8	7296	1056.6	92,119
7	8/2	8/15	14	86.4	8652	63.2	6357	74.8	7504.5	66.6	5065	90.2	8559	1030.2	106,541
8	8/16	8/29	14	90.0	9912	62.4	7231	76.2	8571.5	62.5	5940	90.7	9829	1010.3	120,685
9	8/30	9/12	14	90.8	10729	57.1	7745	73.9	9237.0	68.0	6552	90.4	10643	951.4	129,247
Total	5/10	9/12	126		10729		7745		9237.0		6552		10643		129,247

TABLE XV

TEMPERATURES AND RELATIVE HUMIDITY RECORDED AT THE AGRICULTURAL EXPERIMENT STATION AT KNOXVILLE DURING 1963

Period no.	Period		No. of days	Maximum temperature (°F.)		Minimum temperature (°F.)		Mean temperature (°F.)		Dew point temperature (°F.)		Relative humidity (per cent)		Degree-sunshine hours	
	From	To		Mean/day	Cumulated total	Mean/day	Cumulated total	Mean/day	Cumulated total	Mean/day	Cumulated total	Mean/day	Cumulated total	Mean/day	Cumulated total
1	4/20	5/3	14	73.1	1007	46.1	604	59.6	805.5	67.4	943	78.8	1135	800.3	10,929
2	5/4	5/17	14	82.0	2150	56.1	1407	69.1	1778.5	72.4	1967	82.3	2279	959.0	24,518
3	5/18	5/31	14	75.6	3221	54.1	2179	64.8	2700.0	65.7	2875	80.4	3412	984.0	37,564
4	6/1	6/14	14	84.1	4397	60.4	3040	72.2	3718.5	70.7	3872	83.4	4585	1041.8	52,297
5	6/15	6/28	14	80.6	5546	62.7	3935	71.7	4740.5	67.4	4815	81.5	5727	1039.8	67,120
6	6/29	7/12	14	84.0	6715	60.9	4786	72.5	5750.5	69.6	5796	82.0	6872	1046.4	81,649
7	7/13	7/26	14	84.6	7911	64.5	5687	74.6	6799.0	69.6	6761	81.6	8005	1059.7	96,460
8	7/27	8/9	14	88.0	9124	63.8	6567	75.9	7845.5	71.3	7761	80.4	9138	1053.0	106,941
9	8/10	8/23	14	83.8	10324	60.6	7437	72.2	8880.5	70.1	8745	82.1	10265	970.8	120,724
Total	4/20	8/23	126		10324		7437		8880.5		8745		10265		120,724

TABLE XVI

TEMPERATURES AND RELATIVE HUMIDITY RECORDED AT THE AGRICULTURAL EXPERIMENT STATION AT JACKSON DURING 1962

Period no.	Period		No. of days	Maximum temperature (°F.)		Minimum temperature (°F.)		Mean temperature (°F.)		Dew point temperature (°F.)		Relative humidity (per cent)		Degree-sunshine hours	
	From	To		Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total
1	4/20	5/3	14	77.5	1085	54.3	760	65.9	922.5	55.7	780	75.3	1054	885.3	12,394
2	5/4	5/17	14	87.1	2304	60.9	1613	74.0	1958.5	65.4	1696	74.6	2098	1031.0	26,828
3	5/18	5/31	14	90.6	3573	66.5	2544	78.6	3058.5	68.4	2653	74.6	3143	1094.8	42,154
4	6/1	6/14	14	84.6	4757	65.3	3458	74.9	4107.5	68.9	3617	82.7	4301	1080.9	57,287
5	6/15	6/28	14	86.9	5973	64.2	4356	75.5	5164.5	69.1	4584	81.5	5442	1095.2	72,620
6	6/29	7/12	14	90.6	7068	68.3	5183	79.5	6125.5	72.8	5462	82.5	6428	1147.3	86,485
7	7/13	7/26	14	92.7	8366	66.0	6107	79.4	7236.5	72.2	6473	77.1	7508	1127.7	102,274
8	7/27	8/9	14	90.1	9627	65.5	7024	77.8	8325.5	70.5	7460	80.2	8631	1078.8	117,377
9	8/10	8/23	14	94.6	10951	63.1	7908	78.9	9429.5	66.7	8394	72.1	9641	1060.6	132,224
Total	4/20	8/23	126		10951		7908		9429.5		8394		9641		132,224

TABLE XVII

TEMPERATURES AND RELATIVE HUMIDITY RECORDED AT THE AGRICULTURAL EXPERIMENT STATION AT JACKSON DURING 1963

Period no.	Period		No. of days	Maximum temperature (°F.)		Minimum temperature (°F.)		Mean temperature (°F.)		Dew point temperature (°F.)		Relative humidity (per cent)		Degree-sunshine hours	
	From	To		Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total	Mean/ day	Cumu-lated total
1	4/20	5/3	14	72.5	1015	50.5	707	61.5	861.0	52.6	737	80.5	1127	827.5	11,585
2	5/4	5/17	14	84.3	2195	63.1	1591	73.7	1893.0	65.6	1655	80.8	2258	967.8	25,134
3	5/18	5/31	14	76.1	3261	54.9	2360	65.5	2810.5	57.6	2462	79.4	3370	922.6	38,050
4	6/1	6/14	14	89.8	4519	65.7	3280	77.8	3899.5	68.8	3426	74.1	4407	1122.2	53,761
5	6/15	6/28	14	82.9	5680	65.4	4195	74.1	4937.5	67.8	4376	82.5	5562	1075.5	68,819
6	6/29	7/12	14	88.4	6918	66.2	5122	77.3	6020.0	68.8	5339	79.1	6670	1116.5	84,451
7	7/13	7/26	14	87.8	8148	68.4	6080	78.1	7114.0	72.4	6353	85.2	7863	1104.8	99,997
8	7/27	8/9	14	91.6	9430	69.2	7049	80.4	8239.5	74.4	7394	83.7	9035	1115.2	115,610
9	8/10	8/23	14	87.1	10650	62.6	7925	74.8	9287.5	67.4	8338	81.1	10170	1002.4	129,644
Total	4/20	8/23	126		10650		7925		9287.5		8338		10170		129,644

TABLE XVIII

AIR MOVEMENT, RAINFALL, OPEN PAN EVAPORATION, AND WATER LOSS FROM ATMOMETERS AT THE AGRICULTURAL EXPERIMENT STATION AT KNOXVILLE DURING 1962

Period no.	Period		No. of days	Air movement (miles)		Rainfall (in.)	Open pan evaporation (inches)		Atmometer evaporation in inches					
									Mean/day			Cumulated total		
	From	To		Mean/day	Cumulated total		Mean/day	Cumulated total	Black	White	B-W	Black	White	B-W
1	5/10	5/23	14	56.7	793.5	1.05	0.28	3.95	36.4	27.2	9.1	509	381	128
2	5/24	6/6	14	34.0	1269.0	1.91	0.28	7.81	42.7	30.7	12.0	1107	811	296
3	6/7	6/20	14	49.1	1956.1	1.90	0.36	12.89	44.2	26.3	17.9	1726	1179	547
4	6/21	7/4	14	13.2	2141.1	1.76	0.13	17.95	51.1	34.9	16.2	2442	1668	774
5	7/5	7/18	14	25.0	2491.3	1.64	0.39	23.45	49.2	38.1	11.1	3131	2202	929
6	7/19	8/1	14	25.1	2842.3	3.84	0.41	29.24	43.4	32.7	10.6	3738	2660	1078
7	8/2	8/15	14	34.2	3321.3	1.87	0.23	32.52	35.1	26.6	8.4	4229	3033	1196
8	8/16	8/29	14	36.2	3828.4	0.00	0.22	35.60	56.5	35.4	21.1	5020	3529	1491
9	8/30	9/12	14	42.7	4212.5	0.67	0.22	37.62	54.7	35.7	19.0	5512	3850	1662
Total	5/10	9/12	126		4212.5	14.64		37.62				5512	3850	1662

TABLE XIX

AIR MOVEMENT, RAINFALL, OPEN PAN EVAPORATION, AND WATER LOSS FROM ATMOMETERS AT THE AGRICULTURAL EXPERIMENT STATION AT KNOXVILLE DURING 1963

Period no.	Period		No. of days	Air movement (miles)		Rainfall (in.)	Open pan evaporation (inches)		Atmometer evaporation in inches					
									Mean/day			Cumulated total		
	From	To		Mean/day	Cumulated total		Mean/day	Cumulated total	Black	White	B-W	Black	White	B-W
1	4/20	5/3	14	35.7	500.0	3.11	0.30	4.21	33.0	18.0	15.0	462	252	210
2	5/4	5/17	14	65.1	1410.8	0.89	0.27	7.98	33.0	18.0	15.0	924	504	420
3	5/18	5/31	14	51.3	2128.5	4.35	0.26	11.59	55.6	36.8	18.8	1702	1019	683
4	6/1	6/14	14	36.3	2636.3	1.00	0.20	14.43	52.9	34.0	18.9	2443	1495	948
5	6/15	6/28	14	38.6	3177.2	1.78	0.19	17.30	47.5	27.1	20.4	3108	1874	1234
6	6/29	7/12	14	48.8	3860.6	3.00	0.22	20.34	59.4	46.4	12.9	3939	2524	1415
7	7/13	7/26	14	45.5	4497.1	1.83	0.26	23.99	52.0	34.5	17.4	4667	3008	1659
8	7/27	8/9	14	91.0	5770.6	2.97	0.24	27.42	58.6	47.5	11.1	5488	3673	1815
9	8/10	8/23	14	43.1	6328.6	0.76	0.23	30.60	61.5	53.8	7.6	6349	4427	1922
Total	4/20	8/23	126		6328.6	19.69		30.60				6349	4427	1922

TABLE XX

AIR MOVEMENT, RAINFALL, OPEN PAN EVAPORATION, AND WATER LOSS FROM ATMOMETERS AT THE AGRICULTURAL EXPERIMENT STATION AT JACKSON DURING 1962

Period no.	Period		No. of days	Air movement (miles)		Rainfall (in.)	Open pan evaporation (inches)		Atmometer evaporation in inches					
									Mean/day			Cumulated total		
	From	To		Mean/day	Cumulated total		Mean/day	Cumulated total	Black	White	B-W	Black	White	B-W
1	4/20	5/3	14	76.0	1064.7	1.97	0.29	4.06	60.1	33.7	26.4	841	472	369
2	5/4	5/17	14	43.7	1676.9	0.00	0.28	8.00	60.1	33.7	26.4	1682	944	738
3	5/18	5/31	14	68.0	2628.7	0.78	0.31	12.37	90.4	69.5	20.8	2947	1917	1030
4	6/1	6/14	14	41.6	3211.6	1.62	0.22	15.52	50.6	34.7	15.9	3656	2403	1253
5	6/15	6/28	14	35.4	3706.6	0.87	0.24	18.84	54.8	39.9	14.8	4423	2962	1461
6	6/29	7/12	14	29.7	4122.1	1.33	0.23	22.04	62.7	36.7	26.0	5301	3476	1825
7	7/13	7/26	14	37.0	4640.5	0.47	0.27	25.86	69.1	34.8	34.4	6269	3963	2306
8	7/27	8/9	14	39.7	5196.1	0.74	0.27	29.64	66.8	27.4	39.4	7205	4347	2858
9	8/10	8/23	14	34.4	5677.2	0.00	0.30	33.86	75.8	42.8	33.0	8267	4947	3320
Total	4/20	8/23	126		5677.2	7.78		33.86				8267	4947	3320

TABLE XXI

AIR MOVEMENT, RAINFALL, OPEN PAN EVAPORATION, AND WATER LOSS FROM ATMOMETERS AT THE AGRICULTURAL EXPERIMENT STATION AT JACKSON DURING 1963

Period no.	Period		No. of days	Air movement (miles)[a]		Rainfall (in.)	Open pan evaporation (inches)		Atmometer evaporation in inches					
									Mean/day			Cumulated total		
	From	To		Mean/day	Cumulated total		Mean/day	Cumulated total	Black	White	B-W	Black	White	B-W
1	4/20	5/3	14	70.6	988.2	3.45	0.18	2.51	69.5	53.0	16.5	880	660	220
2	5/4	5/17	14	59.8	1826.0	0.35	0.24	5.83	73.8	55.4	18.4	1913	1436	477
3	5/18	5/31	14	47.1	2532.5	4.43	0.21	8.81	52.3	38.8	13.5	2645	1980	665
4	6/1	6/14	14	36.8	3048.5	0.04	0.28	12.72	79.8	51.7	28.1	3763	2704	1059
5	6/15	6/28	14			2.60	0.20	15.48	49.4	32.2	17.2	4454	3155	1299
6	6/29	7/12	14			1.30	0.24	18.87	61.5	44.8	16.7	5315	3782	1533
7	7/13	7/26	14			1.23	0.26	22.44	59.3	40.2	19.1	6145	4345	1800
8	7/27	8/9	14			1.03	0.25	25.90	62.1	42.6	19.5	7015	4942	2073
9	8/10	8/23	14			0.00	0.22	29.05	64.6	50.7	13.9	7920	5652	2268
Total	4/20	8/23	126			14.43		29.05				7920	5652	2268

[a]Instrument inoperative.

TABLE XXII

EFFECT OF SOIL MOISTURE ON THE YIELD RESPONSE OF CORN TO APPLIED NITROGEN FERTILIZER AT THE AGRICULTURAL EXPERIMENT STATION AT KNOXVILLE DURING 1962 AND 1963

Irrigation level	Nitrogen rate (lbs./acre)	Yield (bu./acre)		
		1962	1963[a]	2-yr. av.
No irrig.	0	80.6	72.0	76.3
No irrig.	60	121.1	116.8	119.0
No irrig.	120	117.9	142.4	130.2
No irrig.	180	125.7	145.5	135.6
No irrig.	240	119.5	145.8	132.6
No irrig.	300	122.9	140.4	131.6
5 atm. ten.	0	56.7		
5 atm. ten.	60	116.1		
5 atm. ten.	120	126.2		
5 atm. ten.	180	138.9		
5 atm. ten.	240	124.1		
5 atm. ten.	300	135.0		
2 atm. ten.	0	75.9		
2 atm. ten.	60	112.1		
2 atm. ten.	120	115.7		
2 atm. ten.	180	133.8		
2 atm. ten.	240	131.6		
2 atm. ten.	300	129.4		
IRRIGATION MEANS				
0		114.6		
5		116.2		
2		116.4		
L.S.D. (5%)		N.S.		
(1%)		....		
NITROGEN MEANS				
0		71.1	72.0	76.3
60		116.4	116.8	119.0
120		119.9	142.4	130.2
180		132.8	145.5	135.6
240		125.1	145.8	132.6
300		129.1	140.4	131.6
L.S.D. (5%)		8.5	8.5	8.5
(1%)		11.4	11.4	11.4

[a]No irrigations in 1963.

TABLE XXIII

EFFECT OF SOIL MOISTURE ON THE YIELD RESPONSE OF CORN TO APPLIED NITROGEN FERTILIZER AT THE AGRICULTURAL EXPERIMENT STATION AT JACKSON DURING 1962 AND 1963

Irrigation level	Nitrogen rate (lbs./acre)	Yield (bu./acre)		
		1962	1963	2-yr. av.
No irrig.	0	50.7	39.7	45.2
No irrig.	60	75.6	77.2	76.4
No irrig.	120	83.7	108.5	96.1
No irrig.	180	83.8	126.1	105.0
No irrig.	240	84.7	127.0	105.8
No irrig.	300	87.2	114.4	100.8
5 atm. ten.	0	94.6	52.6	73.6
5 atm. ten.	60	98.1	92.8	95.4
5 atm. ten.	120	123.0	123.7	123.4
5 atm. ten.	180	121.2	137.9	129.6
5 atm. ten.	240	120.2	141.3	130.8
5 atm. ten.	300	119.6	150.2	134.9
2 atm. ten.	0	77.4	48.1	62.8
2 atm. ten.	60	108.7	93.9	101.3
2 atm. ten.	120	137.5	137.7	137.6
2 atm. ten.	180	145.0	157.3	151.2
2 atm. ten.	240	151.5	159.5	155.5
2 atm. ten.	300	154.5	151.6	153.0
IRRIGATION MEANS				
0		77.6	98.8	88.2
5		112.8	116.4	114.6
2		129.1	124.7	126.9
L.S.D. (5%)		10.9	N.S.	8.5
(1%)		17.9	....	12.1
NITROGEN MEANS				
0		74.2	46.8	60.5
60		94.1	88.0	91.0
120		114.7	123.3	119.0
180		116.6	140.4	128.5
240		118.8	142.6	130.7
300		120.4	138.8	129.6
L.S.D. (5%)		9.6	9.4	5.7
(1%)		13.7	12.6	7.6