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To the Graduate Council:

I am submitting herewith a thesis written by David E. McKinney entitled "The Effects of Several Climatic Factors and Several Nitrogen and Moisture Levels on the Yield and Evapotranspiration of Corn." 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 Parks
Major Professor

We have read this thesis and recommend its acceptance:

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THE EFFECTS OF SEVERAL CLIMATIC FACTORS AND SEVERAL NITROGEN AND MOISTURE LEVELS ON THE YIELD AND EVAPOTRANSPIRATION OF CORN

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

David E. McKinney

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ABSTRACT

The purpose of this study was to relate evapotranspiration (ET) and yield of corn to several climatic factors and to several treatments of nitrogen and irrigation. The experiments were conducted at Knoxville and Jackson for five seasons. The experimental design was the split plot with three moisture levels for main plots and six nitrogen levels for the splits. Dixie 29 hybrid corn was planted on beds and thinned to 20,000 plants per acre. Moisture readings were made every 7 or 14 days with a neutron moisture meter. Several climatic factors were recorded at the two experiment stations and these were correlated with ET. Correlations were also made for open pan evaporation with ET from several treatments and with the other climatic factors. Yield, water use efficiency and water use for several treatments were analyzed.

All of the climatic factors studied correlated highly with ET and with open pan evaporation. ET from corn was related to open pan evaporation in almost the same way, regardless of the nitrogen or irrigation applied.

Yield increases were noted for each 60 lb. increment of nitrogen added up to 120 lb. at Knoxville, and 180 lb. at Jackson. Water use efficiency was increased by added nitrogen. Yields were increased by irrigation for the five year average at both locations but there were no increases due to irrigation during several of the wetter seasons. Water use was greatest during the time of tasseling, silking and kernel formation. The peak water use was 0.22 inches per day at both locations

for the average. The irrigated plots used about 2 to 4 inches more water than the unirrigated, during a season. Nitrogen had little effect upon total water use but greatly affected water use efficiency.

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CHAPTER I

INTRODUCTION

Irrigation in the humid southeastern United States has been studied with much interest in recent years. Farmers in the region now are using high yielding varieties and higher rates of fertilizers. Their yields are often limited in many years by the amount of water available to the crop. Due to this, studies of irrigation feasibility, requirement, and technique for most of the crops grown in the southeast have been intensified.

Most irrigation experiments, and irrigation practices require a knowledge of the consumptive water use of the crop. This can be estimated with varying degrees of accuracy, by using any of several formulas, or it can be measured by using rainfall and runoff data along with soil water changes for the period of interest. The primary difficulty encountered in earlier studies was that the actual water content of the soil could not be easily or quickly measured. The advent of the neutron moisture meter has enabled researchers to determine soil water content at almost any time and with very little effort and has proven to be as accurate as any other method (31).

The present study was conducted to determine the effects of several climatic factors, nitrogen rates and irrigation levels upon the yield, water use, and water use efficiency of corn. The ultimate goal was to be able to estimate consumptive use from climatic factors such as temperature, solar radiation, humidity, wind, and evaporation from open pan and atmometers. This estimate is derived from regression analysis which is made possible by concurrent data for consumptive use and climatic factors.

CHAPTER II

LITERATURE REVIEW

I. EARLY WORK AND DEFINITIONS

The optimum growth of crop plants upon each unit of land is the chief goal of the agronomist. To do this each factor affecting the plant's growth must be at peak efficiency. The limitations of inadequate plant nutrients have been recognized and studied for centuries, but until recently very little was known about the relationship of water and plants except to know that irrigation was generally beneficial or that plants require water to survive.

The first actual measurements of water requirements of crop plants were conducted by Briggs and Shantz (10) in the early years of this century. They recognized that water loss from their weighing pots was actually two processes, losses from the soil, evaporation, and losses through the plant, transpiration. Since that time it has been found convenient for discussion to lump the two processes together and use the term "consumptive use" or "evapotranspiration" to include both processes. 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 (7).

Potential ET was defined by Penman (40) as the amount of water loss in unit time by a short green crop of uniform height, completely shading the ground, and well supplied with water and plant nutrients. Under these conditions maximum evapotranspiration will occur and the potential will be reached. The potential ET for an area is limited only by the weather conditions at the time, while actual ET is limited also by the soils and plants of the area.

Penman (40) stated that temperature, relative humidity, wind, and relative amount of daylight hours were the meteorological factors having significant influence upon potential ET rates. The incoming energy necessary for the vaporization of water was estimated from temperature and daylight hours. For vapor movement to occur there must be a vapor pressure gradient. Measurement of wind and relative humidity gave reliable estimates of this gradient. When taken together these four meteorological measurements provided good estimates of the amount of ET that occurred.

II. THE PLANT AND ITS CONTROL OF EVAPOTRANSPIRATION

Plant species and crop varieties may have widely different water requirements. In 1914 and 1915, Briggs and Shantz (10) used measured amounts of water to grow several kinds of agronomic crops in iron pots which were weighed periodically. Solar radiation, air temperature, wet bulb depression, wind and evaporation were measured. Their results showed that of the crops studied, barley used the least water and alfalfa used the most. Corn, sudangrass and sorghum all used about the same amounts but variations up to 30 percent were found among the corn varieties studied.

The depth and habit of rooting of a plant has a considerable effect upon the use of soil water by the plant (53). Bennett and Doss (4) found that for cool season forage grasses all of the water used was from the top foot of soil and the rooting depth decreased as the moisture level was increased. Shallow rooting was characteristic of most forage grasses, alfalfa roots often penetrated eight feet or more and corn roots typically were all within the top six feet of the soil (53). The most efficient extraction of water from a given volume of soil was by the fibrous root system typical of the grasses but the tap root system of alfalfa and many other perennials utilized water from depths that could not be reached by a fibrous root system (53).

The moisture extraction pattern for corn changed as the season progressed according to Shaw and Laig (47). They found that until June 14th, all of the water used came from the upper six inches of soil, by June 27th, all of the water used was from the top two feet, but by August 1, 10 percent was being removed from depths of five to six feet. Russell and Danielson (46) studied the moisture extraction pattern of corn and concluded that the zone of soil moisture depletion by corn roots moved downward as the season progressed. They found that on a plastic covered plot nearly all of the water being used after August 23 was from depths greater than four feet.

Transpiration losses may be decreased to some extent by the plant's characteristics. This decrease in transpiration may be brought about when soil water is limited by decreasing the plants surface area which receives the incoming energy. A reflective leaf or canopy may decrease transpiration by decreasing the net receipt of solar radiation (47). An epidermis or cutin layer covering the mesophyll cells is another way that some plants resist dry conditions. This layer increases the internal resistance to water movement, according to Shaw and Laig (47). They also reported that when the water deficit reaches a critical stage characteristic for the species, age, etc., there are turgor induced changes in the stomal openings which increase the resistance to transpiration in the gaseous phase.

III. THE EFFECT OF SOIL PROPERTIES UPON EVAPOTRANSPIRATION

Determinations of ET would be very simple if all soils were uniform. The incoming water and energy is easy to measure and the leaf area or canopy cover can be reliably estimated. ET could be derived from this information by simple bank account procedures, and ET rates and amounts could be easily adjusted to apply to other areas where climatic data are known. But soils have a great modifying effect upon the ET of an area, and the capacity of a soil to provide the water required by the plants growing upon it is a complex determination.

The depth to which roots penetrate varies from soil to soil. Rooting depths may be limited by the physical and chemical properties of the soil. Physical limitations include bedrock, pans, and other layers which physically prevent root penetration. Chemical limitations include layers high in exchangeable hydrogen or aluminum or any other element at toxic levels. In addition, most roots will not penetrate layers in which the oxygen level is below about 6 percent. Soils with water tables and pans have oxygen levels lower than this and root penetration is impeded for this reason (47).

Field capacity is defined as the amount of water remaining in a soil after saturation and free water has been allowed to drain away into a drier soil material beneath, and the wilting point is defined as the water content, on an ovendry basis, at which plants wilt and fail to recover their turgidity when placed in a moist environment. Sandy soils hold less water at field capacity but most of that retained is available for plant use while soils high in clay will retain a high amount of water at field capacity but much of this is bound to the clay particles with such force that plants cannot remove it. In general a loam or silt loam soil will retain the most plant available water (53).

Veihmeyer and Hendrickson (52) concluded that plant transpiration continues at a uniform rate regardless of soil water content up to a point near the permanent wilting point. The more prevalent view is given by Taylor and Haddock (49) who stated that the transpiration of a plant will decrease as the soil water content is decreased.

Soil properties that affect plant growth are responsible for much of the difference in ET between different soil areas, but some soil properties also have modifying effects upon the climatic factors of ET. The aspect and slope of the soil are directly related to the amount of incoming radiation that will be effective as energy for ET. The reflective properties of a soil may also modify the effectiveness of incoming radiation in supplying heat for the vaporization of water (1).

IV. THE EFFECT OF CLIMATIC FACTORS ON EVAPOTRANSPIRATION

Temperature, precipitation, humidity, and growing season are climatic factors which greatly affect ET and may be easily determined. These factors are independent of the soils or the plants and are the source of both the water consumed and the energy responsible for the water movement in the ET process. The effects of the soils and plants upon ET are only as modifiers of these climatic factors (6, 7).

When water is available, the ET rate at a particular time and is a particular area is probably affected more by the temperature than any other factor. Plant growth is slowed at either abnormally high or low temperatures, but in the intermediate range an increase in temperature is accompanied by increased growth and ET rates (6).

The effects of the length of the growing season and the day-length are cumulative. The effects of these factors upon the ET rate have nothing to do with its intensity but they do have considerable effect upon the duration of time that transpiration can take place (1).

Low relative humidity and high air movement are conditions which allow rapid transfer of evaporated or transpired water vapor and maintain a gradient favoring such movement. When the air is still and nearly saturated with water vapor, net vapor movement will be nil and the ET rate will be low (24, 27).

Precipitation characteristics as well as amounts are important to the ET rate. The amount of runoff is determined partly by the rainfall intensity and that which runs off cannot be included in

ET losses. The time of year and the rainfall pattern are also important factors. If an excess of precipitation occurs at one time, the excess above the soil storage capacity, is either lost by deep percolation or by runoff. ET rates are sustained at a high level by frequent wetting of the soil surface because water near the surface is more easily evaporated or consumed by plants (27).

V. MOISTURE STRESS AND EVAPOTRANSPIRATION RATE

Shaw and Laig (47) defined moisture stress as being the result of an imbalance between the supply furnished by the soil water and the amount needed by the plant as determined by the atmosphere, assuming a complete crop cover. They also reported that decreasing the water supply had different effects upon the various plant parts and functions. Some plant processes were insensitive over a wide range of moisture stress while others were distinctly affected. The effects upon photosynthesis and respiration were of the most concern. Photosynthesis was decreased by moisture stress, especially near the wilting point, due to an increase in the resistance to carbon dioxide diffusion. Respiration was often increased as moisture stress was incurred. The net effect was that carbohydrate reserves were quickly depleted.

The yield of grain was decreased most when moisture stress occurred near the time of flowering (5, 44, 47). For species with determinant flowering a short period of moisture stress can reduce yields considerably, while the same stress period will have only slight effect upon indeterminate flowering species (47). Corn and soybeans respectively fit these categories. Moisture stress during the period of silking and tasseling causes the greatest yield depression for corn. Robins and Domingo (44) found that depletion of soil water to the wilting point for one or two days reduced yields by as much as 22 percent, and for a six to eight day period yield dropped by as much as 50 percent. Shaw and Laig (47) reported reductions for multi-ear varieties were much less than for single-ear varieties due to a high number of second ears developed. The multi-ear varieties are noted as being more drought tolerant, but they are susceptible to drought conditions during the grain filling period. Moisture stress delayed the silking date for both varieties.

The occurrence of stress in plants is related to the following factors (14, 47, 51):

1. The amount of water in the soil.
2. The part of this water that is available to plants.
3. The water requirements of the plants.
4. The plants tolerance to low moisture conditions.
5. The evaporative demand due to meteorological conditions.

Studies that relate the ET rate to the soil's water content have reached several conclusions. Thornthwaite (50) proposed a straight line relationship between soil water content and ET which reached zero at 15 bars of tension. Veihmeyer and Hendrickson (52) have stated that the rate of ET remains high until the soil water content approaches the wilting point.

Transpirational decreases as water supplies decrease have been shown in several studies (14, 16, 35). Demead and Shaw (14) showed that for different rates of transpirational demand, the actual ET fell below potential ET at different moisture levels. They assumed that potential ET could be measured by ET at field capacity which was at 36 percent water in the soil used. At the high demand rate, six to seven mm./day, actual ET fell below potential at 0.3 bars of tension or 34 percent water. At the lowest demand rate measured, one to four mm./day, actual fell below potential ET at 12 bars of tension or 23 percent water. At low demand, the ET was related to soil water content in the manner suggested by Viehmeyer and Henrickson, but at high evaporative demand, Thornthwaite's linear relationship was applicable. A curvilinear relationship between ET rates and the soil water content was best suited to fit all situations.

VI. STAGE OF GROWTH AS IT AFFECTS EVAPOTRANSPIRATION

Black (5) stated that the evaporation of water from a soil moist at the surface was about the same as that from bulk water. He further stated that even when plants were introduced onto the soil surface the relationship holds because some of the evaporation from the soil was replaced by the transpiration of the plants. This approximate equality between free water, plants, and soils is only a generality and departures from it may occur due to surface properties. Also, under high evaporative demand, equality would not be maintained because of decrease of turgidity in the plants and closure of the stomata and because of rapid development of a dry layer on the surface of the soil.

This indicates a close relationship between actual ET and open pan evaporation. Doss, Bennett and Ashley (15) found that as the season progressed and the corn crop matured the ratio of ET to open pan evaporation changed considerably. At emergence the ratio was 0.38, during the dough stage it was 1.12, and for the dry shuck stage it was 0.95. It was apparent that the open pan evaporation increased more slowly than the ET rate as the summer progressed. The ET rate of the corn field increased slowly at first and reached a peak of about 0.30 inches/day at the dough stage. They found the ET rate to vary from 0.05 inches/day at emergence in April to 0.30 inches/day in July.

Peck, Vittum and Gibbs (39) did a similar study using several irrigated vegetable crops, including sweet corn, peas and cabbage. They found a more linear relationship for ET rate and open pan evaporation than Doss, Bennett and Ashley (15). The stage of growth and development of the crops affected ET rates during periods of vigorous growth such as occurred for peas in June, sweet corn in July and cabbage during early September. Peak water use during these periods was 0.20 inches per day for peas, 0.17 inches per day for corn and 0.16 inches per day for the cabbage.

Hathcock (24) and Holt (27) computed the ET rate for corn during each of nine 14-day periods during the growing season. Both found the same general trend in the ET rate. The first and last 14-day periods had the lowest ET rates while the fourth and fifth periods in July had the highest ET rate. The ET rates for the other periods were intermediate but showed considerable year to year variability.

VII. PREDICTING EVAPOTRANSPIRATION

Many of the most successful early civilizations prevailed in irrigated regions. These early people knew that the yield of their fields was dependent upon the water they applied but efficiency of the irrigation water in terms of yield per inch of water was of little concern to them. Total yield was their measure of success.

More recently the situation has changed in most of the world, because water is now more precious and often more expensive. Irrigation prevails in regions where it must be moved hundreds of miles before it may be applied. People other than the irrigator are concerned that water supplies are used wisely. For these and other reasons, the modern irrigator finds he must use the water available to him more judiciously than in early times. The best amount of water to apply and the best time to apply it must be known. It would be foolish to apply water when the soil is supplying the proper amount, or at a time when the crop requires no additional water, or has wilted beyond recovery. The irrigator must be able to determine when the natural supply of water becomes limiting and supplemental water is needed. Thus estimates of the amount of water lost from an area in a period of time must be available so that the amount remaining for crop utilization will be known. Many methods and formulas have been devised that will do this.

In this country most of the evapotranspiration studies have been conducted since the early part of this century in the irrigated valleys of the west. For many years engineers of that area have depended upon temperature records to estimate valley consumption (7).

Blaney (6) reported that in 1924 Hedke developed the effective heat method for predicting ET in the Rio Grande Valley. By this method consumptive use (ET) was estimated by using the heat units available to the crops of a particular valley. The basic assumption was that there was a linear relation between the quantity of heat available and the amount of water consumed. The Bureau of Reclamation uses a somewhat similar method developed by Lowry and Johnson but modified it by using accumulated daily maximum temperature above 32 degrees fahrenheit (6, 7).

Blaney and Criddle (7) developed a procedure which used a formula to correlate existing ET data for various crops with monthly temperature, percentage of daylight hours, precipitation, frost-free (growing) period or irrigation season. The coefficients they developed were used to transpose the consumptive use data for a given area to other areas where only climatological data are available. Temperature and precipitation records are available for nearly every region of the world. The actual hours of sunlight are not known for most areas but theoretical daytime hours for each day are directly related to the latitude and may be used in place of actual data. Another requirement of this method is to know the approximate consumptive use by the crop in question. These values vary as the plant matures but are available for the common crops.

Studies by Penman in England sought to relate estimated open pan evaporation to ET rates (42). His basic assumption was that evaporation is an energy change of the incoming solar energy. Energy changes are due to reflection, back radiation, evaporation, or sensible heat transfer. He states that the energy changes will be the same for all areas under the same climatic conditions, if the plant cover is complete and water is available regardless of the type of plant or the soil type. Penman's method employs mean temperature, mean air vapor-pressure, mean wind force, and mean sunshine hours to give an estimate of the amount of water evaporated from an open evaporating pan (42). He found that this estimate was useful in preducting ET rates and water content of the soil if it was adjusted for root volume and soil water supply as estimated by spring rainfall (40).

Thornthwaite's classification of the climates of the world was developed because he believed that rainfall alone was not sufficient reason for classifying an area as humid, or dry (50). His solution to the problem was to include ET as well as rainfall in the classification. The problem he faced was that rainfall was easily measured but ET measurements were very difficult and generally unavailable. Estimates of potential ET were used because of this lack of actual data. Thornthwaite made his estimate of potential ET from two measurements, mean monthly temperature, and day-length as determined by latitude.

His method has the advantage that these records are available for any area and it has proven satisfactory in many places.

Van Bavel and Wilson (51) described a method of estimating soil water content by using a bank account approach. This method was actually not an estimate of ET but rather an estimate of the amount of water in the soil at a given time. This makes it more applicable to irrigation uses. The process involves measurements of water holding capacity and rooting limitations of the soil, measurements of rainfall and runoff, and estimates of ET for the crop to be grown. After field capacity is reached the water supply record is maintained simply by adding rainfall and irrigation and subtracting ET and other losses.

Livingston (34) discovered that black and white atmometers respond to available solar energy by evaporation of water from porous clay cups. The white atmometer will reflect 90 percent or more of the solar radiation falling on it while the black atmometer will absorb 90 percent or more of this radiation. The difference of water loss between the two will be directly related to the intensity of the solar energy radiation. Janes (29) stated that potential ET depends to a large extent on the amount of sunshine or radiant energy received at plant height and that differences in water loss from black and white atmometers (B-W) is directly proportional to the amount of sunshine. He proposed a simple formula for potential ET whereby the difference (B-W) was the only measurement needed.

VIII. MEASURING EVAPOTRANSPIRATION

Measurements of ET can be made by using any of several methods. For all of these the amount of water added to the soil must be known as well as the soil's water content at various times. The added water is determined by using rainfall and irrigation records but the soil's water content is rather difficult to determine. Four methods have proven satisfactory. They are: taking samples at various depths and drying them to determine weight loss, growing the plants in pots or lysimeters which are weighed periodically, by using any of several kinds of resistance blocks, and more recently by using the neutron scattering technique.

The sampling method is very time consuming. The lysimeter method involves large and expensive equipment and is adaptable only to certain experimental conditions (36). The use of resistance blocks which respond to changes in soil water content has proven to be quite adaptable to many situations but there has been some concern for their accuracy (31). The neutron scattering technique is quick and accurate but involves some skill in operation and a considerable original expense (9, 31, 36).

CHAPTER III

MATERIALS AND METHODS

This study involved the accumulation of water use records for corn grown under several nitrogen and moisture levels at Knoxville and Jackson. Concurrent data for several climatic factors were also kept and correlations were computed between ET and each of the climatic factors on both a seasonal and 42-day period basis. Open pan evaporation was correlation with ET from several treatments and with the climatic factors under study. Water use was summarized by 14-day periods for several of the treatments. Analyses of variance were made for yield and for water use and water use efficiency was derived for three of the nitrogen levels.

The experiments were conducted for five years on Sequatchie fine sandy loam at the Plant Science Farm, Knoxville, and on Memphis silt loam at the West Tennessee Experiment Station, Jackson. The soils are deep, well drained and medium textured on nearly level sites. There are no restrictions to root growth and both have a high water holding capacity. Properties of these soils as given by Hathcock (24) and Holt (27) are in the Appendix (Table A-1).

The experiments were begun in 1962 and concluded in 1966 at Jackson and in 1967 at Knoxville. Data for 1966 at Knoxville was omitted because hail destroyed the first planting.

A split-plot design with three replications was used. The main plots were 120 by 35 feet at Knoxville and 60 by 70 feet at Jackson with subplots of 20 by 35 feet at both locations. The moisture treatments applied to the main plots, were no irrigation and irrigation when the surface foot of soil reached 2 bars tension, and irrigation at 5 bars tension. Each of these main plots was divided into six subplots which were treated with one of the following nitrogen rates: 0, 60, 120, 180, 240, or 300 pounds of actual nitrogen (N) per acre.

To insure that potash and phosphate were not limiting, 500 pounds per acre of 0-20-20 was broadcast on the plots. The nitrogen treatments were applied as ammonium nitrate and all fertilizer was disked in before beds were constructed.

The variety of corn planted was Dixie 29, a full-season, white hybrid. It was planted on beds with 30 inches between rows and thinned to obtain a population of 20,000 plants per acre. Furrow irrigation by gated pipe was used on the irrigated plots. Measurements and observations were begun soon after planting and continued until maturity.

I. MOISTURE MEASUREMENT EQUIPMENT

The neutron scattering method was used to determine the soil water content. There are several advantages of the neutron scattering method. The soil profile is disturbed only when the access tubes are installed and the disturbance to the adjacent soil is minimal. Little time and effort is required to make the readings and many readings can be made in one day. When the accuracy of other methods were compared, the neutron scattering method was found to be as accurate as any method tested (9, 31, 36).

The neutron scattering method of measuring soil water content is fairly simple in theory. A fast neutron source is lowered through an access tube to the desired level. As the fast neutrons collide with hydrogen ions of the soil system, they are reflected toward a counter tube, lose some of their energy and become thermal neutrons. Thermal neutrons are absorbed by the boron trifloride gas of the detector tube and in the process alpha particles are emitted which are detected and counted by the scaler. The slowing of fast neutrons which produces the thermal neutrons and subsequent alpha particles is directly proportional to the number of hydrogen atoms in the soil. Since most of the hydrogen atoms are in water molecules in most soils, the counts of alpha particles recorded on the scaler is related to the soils water content.

The area of scatter and the range of detection depend upon the water content of the soil. In a dry soil the range is increased because there is less resistance to the penetration of fast neutrons. The counts per unit of time are converted into water percentage by volume and the actual volume measured is inconsequential. The conversion of counts per minute into percent water by volume is accomplished by using a master calibration curve furnished by the equipment manufacturer. Except for soils very high in sand, clay or organic matter, the same curve may be used. The manufacturer's curve has given good results with Tennessee soils.

The equipment used in this study was made by the Nuclear Chicago Corporation, Des Plaines, Illinois. It consisted of a model 2800 portable scaler, a model P-19 subsurface probe, and a model P-21 surface probe. The scaler is an electronic counter and the probes contain the fast neutron source (Ra-Be), and the detector tube.

II. MOISTURE MEASUREMENT

The moisture readings were made in seven or fourteen-day intervals if equipment maintenance and weather conditions permitted. Errors due to equipment calibration or malfunction in the field were minimized by making frequent readings of paraffin standards and adjusting the equipment if necessary. Subsurface readings were taken by dropping the P-19 probe into a three-inch aluminum pipe and recording a 30 second count at six-inch intervals to a depth of 54 inches. The surface nine inches of soil was measured with the P-21 probe and taken to be the average of two one minute counting periods, one on top of the bed and one in the middle between corn rows. The aluminum tubes were installed by auger each year after the beds were constructed. The moisture readings were made in two replications of each moisture level and at the 0, 120 and 300 pound rates of nitrogen.

The water use during each two-week period was determined as follows: The counts per minute were converted into percent water for each reading interval of each tube every time the measurements were made. At the end of the season the readings for each tube were arranged chronologically and the difference between successive readings was determined at each reading interval. These differences were accumulated for each period and were multiplied by six for the deep readings, and by nine for the surface, to represent the six or nine inches of the soil profile. The total accumulated difference for each tube plus any rainfall or irrigation that occurred were divided by the number of days in the period to determine the daily water use. Runoff and deep percolation water losses were considered neglible.

III. WEATHER RECORDS AND OBSERVATIONS

The following weather factors were observed or obtained from the climatological records of the respective experiment stations:

1. Daily maximum and minimum temperatures.

2. Daily rainfall using a standard eight inch circular rain gauge.

3. Air movement by totalizing anemometer.

4. Relative humidity and dewpoint using psychrometer.

5. Open pan evaporation using standard U. S. Weather Bureau pan.

6. Evaporation from black and white Livingston atmometer bulbs (except for 1967).

7. Total solar radiation using pyrheliograph (except for 1962 and 1963).

8. Sunshine hours from World Almanac (in 1962 and 1963).

In addition to these data, records of daily maximum and minimum temperatures were recorded during the growing season in four of the subplots. The thermometers were located in weather boxes 18 inches above the soil surface. Daily readings were made each morning except for weekends.

Except for 1967, water losses from black and white Livingston atmometers were recorded within the experimental plots. The atmometers had a uniform coefficient of 0.77 and the quantity of water required to refill the reservoir bottles was taken to be the evaporated water loss.

IV. REGRESSION EQUATIONS

Regression analyses were made between average ET and the climatic factors on a cumulative basis. The selected climatic factors used in the regression analyses included: water loss from black atmometers, from white atmometers and the difference black minus white (B-W), maximum, mean, and dew point temperatures, degree-sunshine hours, total solar radiation, relative humidity and wind. Some of the climatic records were available for only four of the five years. When multiplied by the cumulative value for the independent variable the regression coefficients give reliable estimates of ET, which permit calculation of the soil water content. Moisture measurements are not necessary but the period must begin at a time when the soil's water content is known if it is to be estimated. The water content at field capacity is a value that is known for most soil series in Tennessee. It may be safely assumed that the soil is at its field capacity value in the early spring or any other time following a long wet period.

V. YEARLY RECORDS OF ET AND CLIMATIC FACTORS

The main aim of this study was to summarize and analyze the results of five years of ET and climatic records. ET data for 1967 at Knoxville and for 1966 at Jackson and records of the corresponding climatic factors are included in the Appendix (Tables A-2 through A-9). Similar records for the years 1962 and 1963 may be found in B. E. Holt's thesis (27) and for 1964 and 1965 in B. R. Hathcock's thesis (24).

CHAPTER IV

RESULTS AND DISCUSSION

Values for correlation coefficients and standard errors of the regression estimate are quoted throughout this section. These values, along with regression equations and standard errors of the regression coefficient are explained as follows: The correlation coefficients show the degree of the linear relationship between the two variables. The standard error of the estimate gives an indication of how well the actual observations were explained by the regression line. The equation gives the base value and the slope of the regression line and the standard error of the regression coefficient measures the variability associated with it. High correlations, and low standard errors of the estimate and of the regression coefficient were obtained in most cases. Accuracy of predictions obtained from the regression equations will be directly related to these values. The terms highly significant and significant are used hereafter to be the 0.01 and 0.05 level of probability, respectively.

I. CORRELATIONS OF ET WITH SEVERAL CLIMATIC FACTORS, CUMULATED FOR 126 DAYS

The high correlations between cumulative ET and the several climatic factors studied were to be expected. ET involves basically two processes, the vaporization of water and the movement of this water vapor into the atmosphere. Maximum and mean temperatures, total solar radiation and degree-sunshine hours are all measurements which are directly related to the energy supply available for water vaporization. Dew point temperatures and relative humidity measurements are directly related to the vapor pressure gradient necessary for vapor movement. Wind will have a considerable effect upon the maintenance of the vapor pressure gradient by its removal of evaporated water away from the evaporating surface. Measurements of water loss from atmometers are essentially measurements of the evaporation potential. Cumulative ET should be highly correlated with these measurements, and, in fact, highly significant correlations were found at both locations for all the climatic factors studied (Tables 1 and 2). At Knoxville, the highest correlation (0.9935) of cumulative ET with any climatic factor was with cumulative relative humidity. At Jackson this correlation was 0.9861, slightly lower than at Knoxville. The standard errors of the stimate were 0.7656 at Knoxville and 1.1706 at Jackson for cumulative relative humidity.

Cumulative ET was highly correlated with cumulative water loss from atmometers in all cases. Coefficients of correlation between cumulative water loss from atmometers with cumulative ET were 0.9905, 0.9724 and 0.9630 for black, white and "B-W" at Knoxville. At Jackson, they were 0.9783, 0.9435 and 0.9558 for these variables with higher standard errors of the estimate.

Cumulative maximum, mean and dew point temperatures were highly correlated with cumulative ET at both locations. The correlation

TABLE 1

COEFFICIENTS OF CORRELATION, VALUES OF r^2 OR R^2, STANDARD ERROR OF REGRESSION COEFFICIENTS STANDARD ERROR OF ESTIMATE, AND EQUATION DESCRIBING THE RELATIONSHIP BETWEEN VARIABLES UNDER STUDY, IN CORN ON SEQUATCHIE FINE SANDY LOAM AT KNOXVILLE

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative ET in acre inches					
X_1	Cumulative relative humidity percentage*	.9935	.9870	0.00004	.7656	Y = -0.817 + 0.0021X
X_2	Cumulative water loss from black atmometer in ml.*	.9905	.9811	0.00009	.9249	Y = -0.584 + 0.0038X
X_3	Cumulative water loss from white atmometers in ml.*	.9724	.9456	0.00023	1.5715	Y = 0.095 + 0.0056X
X_4	Cumulative B-W in ml.*	.9630	.9272	0.00049	1.8154	Y = -0.368 + 0.0103X
X_5	Cumulative maximum temperature in °F	.9714	.9436	0.00008	1.6668	Y = -0.348 + 0.0022X
X_6	Cumulative mean temperature in °F	.9707	.9423	0.00009	1.6868	Y = -0.256 + 0.0025X
X_7	Cumulative dew point temperature in °F*	.9593	.9202	0.00013	1.9030	Y = 0.459 + 0.0026X
X_8	Cumulative total solar radiation in g. cal./cm.^{2}	.9761	.9528	0.00001	1.5252	Y = -0.839 + 0.0004X
X_9	Cumulative degree - sunshine hours*	.8343	.6961	0.00002	3.7140	Y = 2.630 + 0.0002X
X_{10}	Cumulative wind in miles per day	.8931	.7975	0.05514	3.5279	Y = 1.518 + 0.0042X

TABLE 1 (continued)

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative open pan evaporation in inches					
X_1	Cumulative relative humidity percentage*	.9534	.9090	0.00016	3.0651	Y = 0.0928 + 0.0030X
X_2	Cumulative water loss from black atmometers in ml.*	.9279	.8610	0.00037	3.7890	Y = 0.857 + 0.0054X
X_3	Cumulative water loss from white atmometers in ml.*	.9558	.9136	0.00044	2.9880	Y = 1.003 + 0.0083X
X_4	Cumulative B-W in ml.*	.9418	.8870	0.00159	5.8372	Y = 2.755 + 0.0132X
X_5	Cumulative maximum temperature in °F	.9394	.8825	0.00016	3.3452	Y = 0.305 + 0.0029X
X_6	Cumulative mean temperature in °F	.9369	.8778	0.00019	3.4104	Y = 0.4961 + 0.0033X
X_7	Cumulative dew point temperature in °F*	.8514	.7249	0.00037	5.3307	Y = 3.174 + 0.0035X
X_8	Cumulative total solar radiation in g. cal./cm.^{2}	.9360	.8761	0.00003	3.4333	Y = -0.171 + 0.0005X
X_9	Cumulative degree - sunshine hours*	.9490	.9006	0.00002	3.2041	Y = 2.621 + 0.0003X
X_{10}	Cumulative wind in miles per day	.8849	.7830	0.00049	4.5440	Y = 0.329 + 0.0061X
Y	Cumulative open pan evaporation in inches					
X_1	Cumulative ET in acre inches; no irrigation	.8443	.7128	0.12027	5.2289	Y = 2.735 + 1.2425X

TABLE 1 (continued)

Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
X_2 Cumulative ET in acre inches; irrigated at 2 bars tension	.8720	.7604	0.09892	4.7758	$Y = 2.834 + 1.1556X$
X_3 Cumulative ET in acre inches; no nitrogen	.8709	.7584	0.10573	4.7947	$Y = 2.371 + 1.2288X$
X_4 Cumulative ET in acre inches; 120 lb. nitrogen	.8663	.7505	0.10200	4.8746	$Y = 2.599 + 1.1598X$
X_5 Cumulative ET in acre inches; 300 lb. nitrogen	.8793	.7731	0.10284	4.6477	$Y = 2.388 + 1.2448X$
X_6 Cumulative ET in acre inches; average all treatments	.8733	.7626	0.10331	4.7534	$Y = 2.436 + 1.2145X$

*Includes data for only four years.

TABLE 2

COEFFICIENTS OF CORRELATION, VALUES OF r^2 OR R^2, STANDARD ERROR OF REGRESSION COEFFICIENTS, STANDARD ERROR OF ESTIMATE, AND EQUATION DESCRIBING THE RELATIONSHIP BETWEEN VARIABLES UNDER STUDY, IN CORN ON MEMPHIS SILT LOAM AT JACKSON

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative ET in acre inches					
X_1	Cumulative relative humidity percentage*	.9861	.9724	0.00007	1.1706	Y = -1.160 + 0.0023X
X_2	Cumulative water loss from black atmometers in ml.	.9683	.9376	0.00012	1.7315	Y = -1.527 + 0.0030X
X_3	Cumulative water loss from white atmometers in ml.	.9435	.8902	0.00023	2.2967	Y = -1.083 + 0.0042X
X_4	Cumulative B-W in ml.	.9558	.9135	0.00041	2.0388	Y = -1.001 + 0.0088X
X_5	Cumulative maximum temperatures °F	.9864	.9730	0.00005	1.1387	Y = -1.169 + 0.0021X
X_6	Cumulative mean temperatures °F	.9880	.9761	0.00006	1.0709	Y = -1.105 + 0.0024X
X_7	Cumulative dew point temperatures °F*	.9885	.9771	0.00007	1.0676	Y = -0.951 + 0.0028X
X_8	Cumulative total solar radiation in g. cal./cm.^{2}*	.8905	.7930	0.00004	3.1678	Y = 0.396 + 0.0004X
X_9	Cumulative degree - sunshine hours	.9364	.8769	0.00001	2.4734	Y = 0.283 + 0.0002X
X_{10}	Cumulative wind in miles per day	.8767	.7686	0.00035	3.3345	Y = -1.234 + 0.0042X

TABLE 2 (continued)

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative open pan evaporation in inches					
X_1	Cumulative relative humidity percentage*	.9838	.9677	0.00009	1.6572	Y = 0.512 + 0.0030X
X_2	Cumulative water loss from black atmometers in ml.	.9901	.9803	0.00008	1.3006	Y = -0.191 + 0.0041X
X_3	Cumulative water loss from white atmometers in ml.	.9692	.9393	0.00023	2.2811	Y = 0.337 + 0.0058X
X_4	Cumulative B-W in ml.	.9727	.9461	0.00044	2.1486	Y = 0.608 + 0.0120X
X_5	Cumulative maximum temperature in °F	.9929	.9858	0.00004	1.1042	Y = 0.566 + 0.0028X
X_6	Cumulative mean temperature in °F	.9912	.9825	0.00007	1.2258	Y = 0.707 + 0.0032X
X_7	Cumulative dew point temperature in °F*	.9927	.9854	0.00008	1.1139	Y = 0.676 + 0.0037X
X_8	Cumulative total solar radiation in g. cal./cm.^{2}*	.9532	.9086	0.00003	2.7816	Y = 1.538 + 0.0005X
X_9	Cumulative degree - sunshine hours	.9539	.9099	0.00001	2.7731	Y = 2.0866 + 0.0002X
X_{10}	Cumulative wind in miles per day	.8914	.7945	0.00044	4.1981	Y = 0.304 + 0.0057X

TABLE 2 (continued)

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative open pan evaporation in inches					
X_1	Cumulative ET in acre inches; no irrigation	.9595	.9206	0.06200	2.6110	Y = 2.617 + 1.3808X
X_2	Cumulative ET in acre inches; irrigated at 2 bars tension	.9824	.9651	0.03400	1.7286	Y = 2.647 + 1.1929X
X_3	Cumulative ET in acre inches; no nitrogen	.9747	.9500	0.04700	2.0730	Y = 2.420 + 1.3500X
X_4	Cumulative ET in acre inches; 120 lb nitrogen	.9840	.9682	0.03600	1.6520	Y = 2.390 + 1.3120X
X_5	Cumulative ET in acre inches; 300 lb nitrogen	.9749	.9504	0.04510	2.0600	Y = 2.830 + 1.2900X
X_6	Cumulative ET in acre inches; average all treatments	.9777	.9559	0.04282	1.9460	Y = 2.578 + 1.3069X

*Includes data for only four years.

coefficients for these factors at Knoxville were 0.9714, 0.9707 and 0.9593 with standard errors of the estimate of 1.6668, 1.6868 and 1.9030 for maximum, mean and dew point temperatures, respectively. The corresponding values for Jackson were slightly higher for the correlation coefficients and slightly lower for the standard errors of the estimate.

Cumulative total solar radiation had a correlation of 0.9761 with cumulative ET at Knoxville and 0.8905 at Jackson. The standard errors of the estimate were slightly lower at Knoxville. Correlation coefficients of 0.8343 and 0.9364 between cumulative degree-sunshine hours and cumulative ET were calculated for Knoxville and Jackson, respectively. Cumulative wind had highly significant correlations with cumulative ET at both locations.

These results indicate that many of the climatic factors studied will give reliable estimates, or predictions, of ET. Those with the highest correlations and the lowest standard errors of the estimate would be expected to give the most accurate estimate of ET. At Jackson, dew point temperatures, mean temperatures, maximum temperatures, and relative humidity should give the most reliable estimates of ET in that order. The climatic factors at Knoxville had very high correlations with ET and low standard errors of the estimate with the exceptions of wind speed and degree-sunshine hours.

The regression formulas given in Tables 1 and 2 may be used to predict ET for a period of time, and to estimate the soil's water content. These equations may be used in lieu of actual soil moisture measurements by starting the climatic measurements and calculations when the soil water level is at field capacity. By multiplying the observed climatological data with the appropriate regression equation, the ET can be predicted for any particular period. The amount of water present in the soil at the beginning of the period, in this case the field capacity water content, is taken as a base amount. Additions due to rainfall or irrigations, and deductions for the predicted ET from this base amount would indicate the amount of water in the soil at any later date. Runoff losses must be subtracted, but in many irrigation situations they may be considered negligible. Irrigation could be started when the soil water reached a predetermined level.

The factor selected for the prediction will depend not only upon the degree of correlation but also upon the availability of the data for that factor. The proximity to a weather station must be considered because of the variability of these weather factors from place to place. Records of several of the factors used are kept at only a few weather stations in Tennessee so these factors might not be as useful as other factors which are recorded at a closer station.

In many situations one could make a good prediction of ET by using maximum and minimum thermometers with the regression formula. A rain gauge could be installed at the same location so that soil moisture additions could be accurately recorded. The cost of these items is small and proper use apparently gives a reliable estimate of ET in corn.

II. CORRELATION OF ET WITH SEVERAL CLIMATIC FACTORS, CUMULATED IN 42-DAY PERIODS

Regression analyses, similar to those presented in Tables 1 and 2, pages 27 and 30, were made for several of the climatic factors on a 42-day basis. The 126-day season was divided into three 42-day periods. In Table 3, one regression coefficient is given for the first 42 days after planting, another for 43 to 84 days and a third for 85 to 126 days after planting. The standard errors of regression coefficient, correlacoefficients, and standard errors of the estimate are included in Tables A-10 through A-15 of the Appendix.

During the first third of the season, the soil water content is generally high which contributes to a steep regression line, but the crop is young and much of the soil is bare which tends to lower the regression line. During the middle part of the season the soil is mostly shaded by green plants at the peak of their moisture use. The regression coefficient is higher here than for any period. In the last third of the season the soil is generally at its driest and the crop is maturing and turning brown. The regression coefficient for this period will be lower than the previous one.

The regression coefficients of Table 3 should be higher for the middle period and lower for the first and last period than those of Tables 1 and 2, pages 27 and 30. These coefficients should give more accurate estimates of ET for a specific part of the growing season than those of Tables 1 and 2, which include the entire season. This is

TABLE 3

REGRESSION COEFFICIENTS FOR SOME CLIMATIC FACTORS WITH ET IN CORN FOR THREE PERIODS DURING THE GROWING SEASON

Variables	At Knoxville			At Jackson		
	0-42 days	43-84 days	85-126 days	0-42 days	43-84 days	85-126 days
Y Cumulative ET						
X_1 Cumulative relative humidity percentage	0.0020	0.0022	0.0018	0.0019	0.0025	0.0014
X_2 Cumulative water loss from black atmometers in ml.	0.0035	0.0042	0.0026	0.0021	0.0027	0.0009*
X_3 Cumulative water loss from white atmometers in ml.	0.0057	0.0055	0.0024	0.0028	0.0025	0.0001*
X_4 Cumulative B-W in ml.	0.0077	0.0079	0.0043	0.0061	0.0121	0.0076
X_5 Cumulative maximum temperatures °F	0.0020	0.0021	0.0017	0.0017	0.0024	0.0013
X_6 Cumulative mean temperatures °F	0.0023	0.0023	0.0019	0.0020	0.0027	0.0016
X_7 Cumulative dew point temperatures °F	0.0025	0.0018	0.0010*	0.0022	0.0032	0.0019
X_8 Cumulative solar radiation in g. cal./cm.^{2}	0.0003	0.0003	0.0002	0.0002	0.0002*	0.0001*

*Correlations not significant at 0.05 level.

because the seasonal water use doesn't progress in a strict linear fashion with regard to any of the climatic factors, and shorter periods of time will eliminate some of this seasonal variability. If these ET estimates are to be used to determine the soil's water content, it must be remembered that the soil water content at the beginning of the period must be known.

Several non-significant correlations were obtained in the last 42-day period. These are partially explained by the year to year variability of crop maturity and soil water content during this period. Wind and degree-sunshine hours were not included at either location, due to low correlations during the last two periods.

III. CORRELATIONS OF OPEN PAN EVAPORATION WITH SEVERAL CLIMATIC FACTORS

All of the correlation coefficients between open pan evaporation and the several climatic factors were highly significant at both locations. At Knoxville, all of the correlation coefficients were less than 0.9500 except for relative humidity (0.9634) and water loss from white atmometers (0.9558), but at Jackson the correlations were all greater than 0.9500 except for wind. The highest correlation obtained at Jackson was with maximum temperatures (0.9929). Wind showed the lowest correlated relationship with open pan evaporation of any factor at both locations. The correlations for wind were 0.8849 at Knoxville and 0.8914 at Jackson. The standard errors of the estimate were considerably higher at Knoxville (Tables 1 and 2, pages 27 and 30).

TABLE 5

AVERAGE MEASURED EVAPOTRANSPIRATION FOR SELECTED TREATMENTS IN CORN ON MEMPHIS SILT LOAM AT JACKSON DURING FIVE SEASONS

Period Number	No Irrigation Mean/ Day	No Irrigation Cumu-lated	2 Atm. Tension Mean/ Day	2 Atm. Tension Cumu-lated	0 lb. N/A Mean/ Day	0 lb. N/A Cumu-lated	120 lb. N/A Mean/ Day	120 lb. N/A Cumu-lated	300 lb. N/A Mean/ Day	300 lb. N/A Cumu-lated	Average of All Treatments Mean/ Day	Average of All Treatments Cumu-lated
	Evapotranspiration in Acre Inches											
1	.11	1.51	.11	1.51	.11	1.51	.11	1.51	.11	1.51	.11	1.51
2	.12	3.16	.12	3.16	.12	3.16	.12	3.16	.12	3.16	.12	3.16
3	.15	5.32	.20	6.16	.17	5.48	.17	5.57	.17	5.48	.17	5.48
4	.22	8.34	.26	9.74	.23	8.65	.22	8.68	.22	8.62	.22	8.62
5	.20	11.14	.23	12.94	.20	11.50	.21	11.65	.21	11.61	.21	11.53
6	.20	13.94	.22	16.07	.19	14.22	.23	14.81	.23	14.98	.22	14.61
7	.17	16.38	.21	19.07	.17	16.66	.18	17.39	.20	17.66	.19	17.21
8	.11	17.95	.16	21.31	.14	18.64	.15	19.43	.16	19.84	.15	19.31
9	.09	19.26	.12	23.04	.12	20.27	.10	20.86	.10	21.27	.10	20.80
Total		19.26		23.04		20.27		20.86		21.27		20.80

treatments was 0.22 inches per day at both locations. This peak occurred during the fifth 14-day period at Knoxville and during the fourth and sixth periods at Jackson.

Table 6 for Knoxville and Table 7 for Jackson give the water use by 14-day periods for each nitrogen x moisture treatment. The seasonal water use for each of these treatments is shown. At both locations the non-irrigated treatment with no nitrogen, used the least amount of water and the 2 atmosphere treatment with 300 pounds of nitrogen at Jackson and 120 pounds of nitrogen at Knoxville used the most water.

VI. ET AS INFLUENCED BY NITROGEN AND MOISTURE LEVELS

The water used during each year at both locations for the 0, 120 and 300 pounds per acre of nitrogen and for the unirrigated and two bars of tension treatments were subjected to analysis of variance (Table 8). The F test showed that there was a highly significant difference between the ET which occurred at the two moisture levels. There was also a highly significant difference in the amount of ET that occurred during the five growing seasons of the study. The effects of the three nitrogen levels and the nitrogen with moisture level interaction upon the ET rate were also tested but were not significant.

VII. WATER USE EFFICIENCY AS INFLUENCED BY NITROGEN LEVELS

Water use efficiency is a ratio computed by dividing inches of water used into bushels of corn produced. The bar graph, Figure 1, represents the average water use efficiency at Knoxville and Jackson for the five years of the study.

TABLE 6

AVERAGE MEASURED EVAPOTRANSPIRATION IN CORN UNDER DIFFERENT MOISTURE AND NITROGEN LEVELS ON SEQUATCHIE FINE SANDY LOAM AT KNOXVILLE DURING FIVE SEASONS

	No Irrigation						5 Atmospheres Tension						2 Atmospheres Tension					
	0 lb. N/A		120 lb. N/A		300 lb. N/A		0 lb. N/A		120 lb. N/A		300 lb. N/A		0 lb. N/A		120 lb. N/A		300 lb. N/A	
Period Number	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated
							Evapotranspiration in Acre Inches											
1	.13	1.82	.13	1.82	.13	1.82	.13	1.82	.13	1.82	.13	1.82	.13	1.82	.13	1.82	.13	1.82
2	.17	4.20	.18	4.34	.16	4.06	.17	4.20	.18	4.34	.18	4.34	.18	4.34	.20	4.62	.17	4.20
3	.18	6.72	.19	7.00	.18	6.58	.18	6.72	.18	6.86	.17	6.72	.19	7.00	.19	7.28	.17	6.58
4	.18	9.24	.19	9.66	.18	9.10	.23	9.94	.23	10.08	.20	9.52	.20	9.80	.21	10.22	.20	9.38
5	.21	12.18	.21	12.60	.22	12.18	.22	13.02	.25	13.58	.21	12.46	.22	12.88	.24	13.58	.20	12.18
6	.16	14.42	.20	15.40	.18	14.70	.18	15.54	.18	16.10	.19	15.12	.18	15.40	.20	16.38	.18	14.70
7	.17	16.80	.16	17.64	.17	17.08	.21	18.48	.22	17.50	.23	18.34	.19	18.06	.23	19.60	.22	17.78
8	.15	18.90	.14	19.60	.15	19.18	.15	20.58	.15	19.60	.15	20.44	.16	20.30	.15	21.70	.15	19.88
9	.12	20.58	.12	21.28	.12	20.86	.12	22.26	.13	21.40	.11	21.98	.14	22.26	.15	23.80	.14	21.84
Total		20.58		21.28		20.86		22.26		21.40		21.98		22.26		23.80		21.84

TABLE 7

AVERAGE MEASURED EVAPOTRANSPIRATION IN CORN UNDER DIFFERENT MOISTURE AND NITROGEN LEVELS ON MEMPHIS SILT LOAM AT JACKSON DURING FIVE SEASONS

Period Number	No Irrigation						5 Atmospheres Tension						2 Atmospheres Tension					
	0 lb. N/A		120 lb. N/A		300 lb. N/A		0 lb. N/A		120 lb. N/A		300 lb. N/A		0 lb. N/A		120 lb. N/A		300 lb. N/A	
	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated
	Evapotranspiration in Acre Inches																	
1	.11	1.54	.11	1.54	.11	1.54	.10	1.40	.11	1.54	.11	1.54	.11	1.54	.11	1.54	.11	1.54
2	.12	3.22	.12	3.22	.12	3.22	.11	2.94	.12	3.22	.12	3.22	.12	3.22	.12	3.22	.12	3.22
3	.15	5.32	.16	5.46	.14	5.18	.14	4.90	.15	5.32	.15	5.32	.21	6.16	.19	5.88	.20	6.02
4	.22	8.40	.21	8.40	.21	8.12	.20	7.70	.20	8.12	.20	8.12	.26	9.80	.25	9.38	.25	9.52
5	.19	11.06	.20	11.20	.21	11.06	.20	10.50	.20	10.92	.20	10.92	.22	12.88	.23	12.60	.23	12.74
6	.17	13.44	.21	14.14	.23	14.28	.22	13.58	.25	14.42	.24	14.33	.20	15.68	.22	15.68	.24	16.10
7	.15	15.54	.18	16.66	.18	16.80	.15	15.68	.17	16.80	.22	17.13	.22	18.76	.20	18.48	.22	19.18
8	.10	16.94	.12	18.34	.12	18.48	.17	18.06	.17	19.18	.18	19.65	.16	21.00	.15	20.58	.17	21.56
9	.11	18.48	.08	19.46	.09	19.79	.10	19.46	.10	20.58	.10	21.05	.13	22.82	.13	22.40	.11	23.10
Total		18.48		19.46		19.79		19.46		20.58		21.05		22.82		22.40		23.10

TABLE 8

ANALYSIS OF VARIANCE OF ET FOR NITROGEN AND MOISTURE TREATMENTS AT TWO LOCATIONS DURING FIVE YEARS

Source	Degrees of Freedom	Mean Square	F	Significant at
Location	1	13650.42	0.503	N.S.
Year	4	159454.10	5.875	.01
Moisture	1	1030970.41	37.984	.001
Nitrogen	2	21257.22	0.783	N.S.
Moisture x Nitrogen	2	4336.22	0.160	N.S.
Error	45	27142.06		

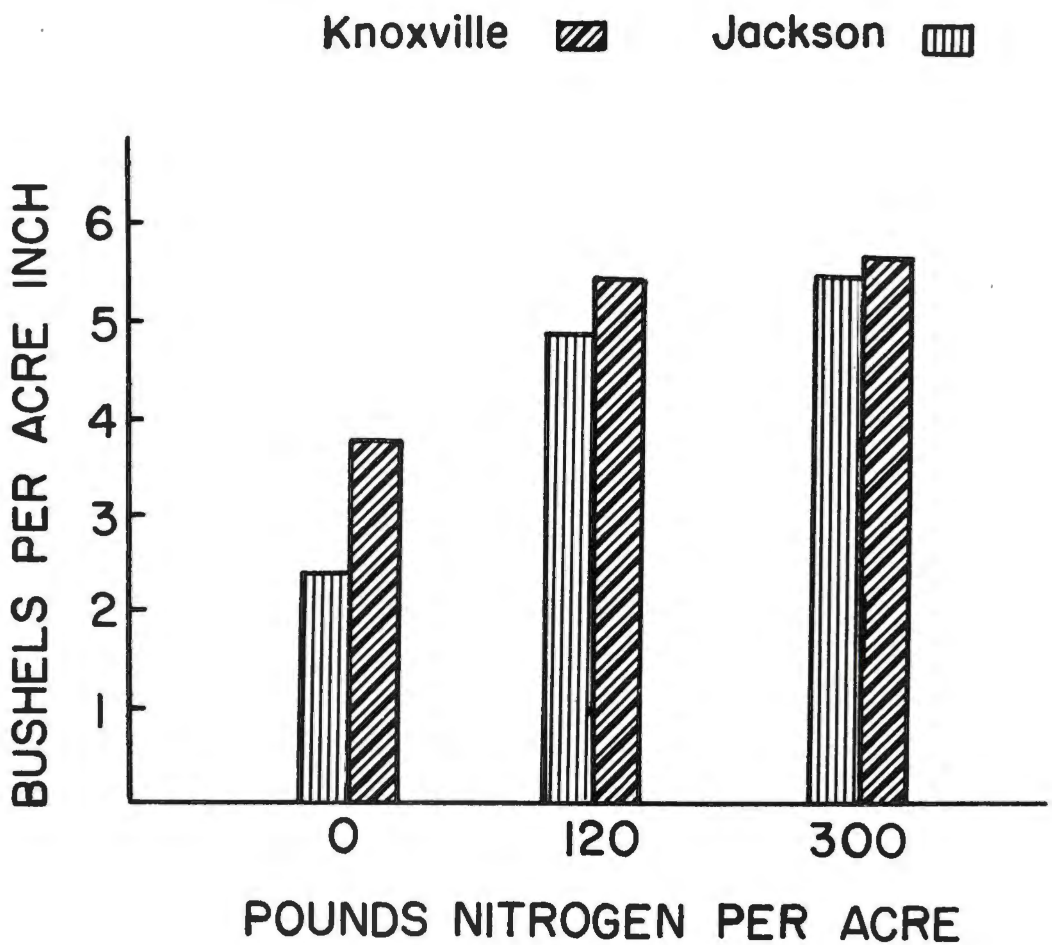

Figure 1. Water use efficiency for corn at three nitrogen levels on Sequatchie fine sandy loam at Knoxville and on Memphis silt loam at Jackson.

At Jackson water use efficiency was doubled by applying 120 pounds of nitrogen per acre. Application of 300 pounds of nitrogen per acre gave an increase in water use efficiency of only 0.6 bushels per acre inch above that obtained when 120 pounds of nitrogen was applied. The water use efficiency ratios for each nitrogen level at Jackson were 2.42, 4.86 and 5.45 for the 0, 120, and 300 pounds per acre rates, respectively.

At Knoxville more favorable ratios were obtained due partly to higher yields at each nitrogen rate. The increase from added nitrogen in water use efficiency obtained in Knoxville was not so great as those at Jackson partially due to the higher initial yields obtained on plots receiving no nitrogen. As the nitrogen level was increased to 120 pounds per acre the water use efficiency ratio increased by 1.64 bushels per acre inch. A further increase to 300 pounds of nitrogen per acre increased the ratio by only 0.2 bushels per acre inch. The ratios obtained at Knoxville were 3.78, 5.42 and 5.62 bushels per acre inch for the 0, 120 and 300 pounds of nitrogen per acre, respectively. The 120 pounds of nitrogen per acre rate resulted in the optimum water use efficiency. The 300 pounds of nitrogen rate gave only a slight increase in water use efficiency above that obtained with 120 pounds of nitrogen. The increased water use efficiency obtained with the applied nitrogen reflect a positive nitrogen-water use interaction. The added nitrogen increased the corn yield obtainable with a given amount of water.

VIII. CORN YIELDS AS INFLUENCED BY NITROGEN LEVELS AND MOISTURE LEVELS

The yields at each location for each year and for the five year average and statistical results are shown in Tables 9 and 10.

Increasing the nitrogen rate gave highly significant increases in yield up to 120 pounds of nitrogen per acre at Knoxville and up to 180 pounds per acre at Jackson. Higher nitrogen rates were of no advantage at either location. At Knoxville the range of yields for the average of all five years was from 80 bushels per acre, with no irrigation or nitrogen, to 128 bushels per acre, with irrigation and 180 pounds of nitrogen per acre. At Jackson a wider range was observed, from 39 bushels with no irrigation or nitrogen to 131 bushels with irrigation and 300 pounds nitrogen per acre. For each year of the study and at both locations highly significant increases in yield were obtained by adding the 60 pounds of nitrogen per acre. At Knoxville highly significant yield increases were also obtained by using 120 pounds of nitrogen for the years 1963 and 1964. Highly significant yield increases were obtained up to 180 pounds of nitrogen per acre at Jackson in each year except during 1962.

The yield response to irrigation was more erratic on a year to year basis than was response to nitrogen, but for the average of all five years, irrigation gave a significant yield increase at Knoxville and a highly significant yield increase at Jackson. On a yearly basis, there were highly significant yield increases due to irrigation at Jackson during 1962 and 1966 and at Knoxville during 1964. There was

TABLE 9

CORN YIELDS ON SEQUATCHIE FINE SANDY LOAM AT KNOXVILLE AS AFFECTED BY SOIL MOISTURE AND NITROGEN

Irrigation	N rate	1962	1963	1964	1965	1967	Average
		Bushels per Acre at 15.5 Percent Moisture					
No irrig.	0	80.6	72.2	70.9	99.3	74.9	79.6
No irrig.	60	121.1	114.9	102.4	116.6	103.8	111.8
No irrig.	120	117.9	144.7	119.9	115.3	111.6	121.9
No irrig.	180	125.7	140.3	116.6	105.8	108.7	119.4
No irrig.	240	119.5	148.3	119.1	113.8	86.4	117.4
No irrig.	300	122.9	138.8	120.0	108.5	83.6	114.8
5 Atm. Ten.	0	56.7	72.4	113.3	90.3	71.7	80.9
5 Atm. Ten.	60	116.1	114.7	122.9	95.2	100.5	109.9
5 Atm. Ten.	120	126.2	143.9	136.3	104.3	111.5	124.4
5 Atm. Ten.	180	138.9	146.9	144.8	93.0	105.4	125.8
5 Atm. Ten.	240	124.1	145.7	138.0	106.2	113.3	125.5
5 Atm. Ten.	300	135.0	143.9	140.1	92.7	116.8	125.7
2 Atm. Ten.	0	75.9	71.5	107.5	94.6	76.7	85.2
2 Atm. Ten.	60	112.1	120.9	138.1	111.0	106.7	117.8
2 Atm. Ten.	120	115.7	138.6	144.4	113.5	118.7	126.2
2 Atm. Ten.	180	133.8	149.3	141.9	102.0	112.6	127.9
2 Atm. Ten.	240	131.6	143.3	134.2	100.8	95.0	121.0
2 Atm. Ten.	300	129.4	138.4	144.3	91.5	106.6	122.0
Response to Nitrogen							
	0	71.1	72.0	97.2	94.7	74.4	81.9
	60	116.4	116.8	121.1	107.6	103.6	113.1
	120	119.9	142.4	133.5	111.0	113.9	124.1
	180	132.8	145.5	134.4	100.3	108.9	124.4
	240	125.1	145.8	130.4	106.9	98.2	121.3
	300	129.1	140.4	134.8	97.6	102.3	120.8
L.S.D. (5 percent)		8.5	8.5	8.0	9.3	12.3	4.2
(1 percent)		11.4	11.4	10.7	12.6	16.6	5.5
Response to Irrigation							
No irrigation		114.6	126.5	108.1	109.9	94.8	110.8
5 Atm. Tension		116.2	127.9	132.6	97.0	103.2	115.4
2 Atm. Tension		116.4	127.0	135.1	102.2	102.7	116.7
L.S.D. (5 percent)		N.S.	N.S.	6.8	N.S.	N.S.	4.4
(1 percent)		N.S.	N.S.	11.2	N.S.	N.S.	N.S.

TABLE 10

CORN YIELDS ON MEMPHIS SILT LOAM AT JACKSON AS AFFECTED BY SOIL MOISTURE AND NITROGEN

Irrigation	N rate	1962	1963	1964	1965	1966	Average
		Bushels per Acre at 15.5 Percent Moisture					
No irrig.	0	50.7	39.7	35.5	33.6	36.6	39.2
No irrig.	60	75.6	77.2	66.3	72.2	61.3	70.5
No irrig.	120	83.7	108.5	67.3	94.9	73.2	85.5
No irrig.	180	83.8	126.1	104.4	113.1	87.0	102.9
No irrig.	240	84.7	127.0	103.7	109.3	85.0	101.9
No irrig.	300	87.2	114.4	104.9	108.9	77.0	98.5
5 Atm. Ten.	0	94.6	52.6	60.5	43.9	40.1	58.3
5 Atm. Ten.	60	98.1	92.8	57.0	75.3	82.0	81.0
5 Atm. Ten.	120	123.0	123.7	99.0	93.8	87.8	105.5
5 Atm. Ten.	180	121.2	137.9	99.1	102.1	94.2	110.9
5 Atm. Ten.	240	120.2	141.3	105.7	103.5	93.8	112.9
5 Atm. Ten.	300	119.6	150.2	101.8	121.3	99.1	118.4
2 Atm. Ten.	0	77.4	48.1	41.7	46.2	35.5	49.8
2 Atm. Ten.	60	108.7	93.9	56.5	80.1	72.9	82.4
2 Atm. Ten.	120	137.5	137.7	97.8	100.7	93.9	113.5
2 Atm. Ten.	180	145.0	157.3	116.1	120.8	111.8	130.2
2 Atm. Ten.	240	151.5	159.5	111.0	112.7	96.5	126.2
2 Atm. Ten.	300	154.5	151.6	117.9	119.4	110.2	130.7
Response to Nitrogen							
	0	74.2	46.8	45.9	41.2	37.4	49.1
	60	94.1	88.0	59.9	75.9	72.1	78.0
	120	114.7	123.3	88.0	96.5	85.0	101.5
	180	116.6	140.4	106.5	112.0	97.7	114.6
	240	118.8	142.6	106.8	108.5	91.8	113.7
	300	120.4	138.8	108.2	116.5	95.4	115.9
L.S.D. (5 percent)		9.6	9.4	9.5	9.2	7.6	3.9
(1 percent)		13.7	12.6	12.8	12.4	10.2	5.1
Response to Irrigation							
No irrigation		77.6	98.8	80.4	88.7	70.0	83.1
5 Atm. Tension		112.8	116.4	87.2	90.0	82.8	97.8
2 Atm. Tension		129.1	124.7	90.2	96.6	86.8	105.5
L.S.D. (5 percent)		10.8	N.S.	N.S.	N.S.	7.3	4.9
(1 percent)		17.9	N.S.	N.S.	N.S.	12.1	6.6

no significant difference between moisture levels except, at Jackson, irrigation at two bars tension significantly increased yields over irrigation at five bars tension during 1962, and for the five-year average.

These results indicate that nitrogen fertilization was beneficial from a yield and water use standpoint at rates of 120 pounds per acre at Knoxville and up to 180 pounds per acre at Jackson. Irrigation gave significant yield increases in several cases and the data for these five years show that irrigation increased corn yields at Jackson. The advisibility of corn irrigation at Knoxville is still in doubt as most of the years were wetter than normal. Irrigation when the soil moisture reaches two bars of tension seems best for Jackson conditions. The economics of irrigation in corn depends upon the cost of water and this varies from location to location.

CHAPTER V

SUMMARY

The purpose of this study was to investigate the relationship between ET and certain climatic factors and to ascertain the influence of nitrogen and moisture levels upon corn yields, water use efficiency and ET. The experiments were conducted for five years at Knoxville and at Jackson. A split plot experimental design with three replications was used with three moisture levels as the main plots and six nitrogen levels for the sub plots.

Dixie 29 hybrid corn was planted on beds 30 inches between rows and thinned to 20,000 plants per acre. The soil water content of two replications was measured during the growing season in the 0, 120, and 300 pound nitrogen plots of each moisture level. The measurements were made every 7 or 14 days by the neutron scattering method and the actual ET was taken to be the difference between consecutive periods plus any rainfall or irrigation that occurred during the period. Records of the selected climatic factors were obtained from the weather stations at the Knoxville and Jackson experiment stations.

The prediction of ET using the climatic factors as a basis for the prediction was one of the main concerns of this study and regression analyses were made for this purpose on a seasonal basis, and on a 42-day basis. All of the climatic factors studied were highly correlated with ET on a seasonal basis. On a 42-day basis, the correlations were highest for the first period and generally decreased the next two periods. Relative humidity, water loss from atmometers, and maximum, mean and dew point temperatures were most highly correlated with ET and should give the best prediction of ET. Solar radiation was highly correlated with ET at Knoxville, but the correlation was lower at Jackson. Degree-sunshine hours and wind were the lowest of the correlations. For the average irrigator, a good prediction of ET can be most easily obtained by using maximum and minimum thermometers with the regression equations.

The relationships of the selected climatic factors to open pan evaporation and of ET from several treatments to open pan evaporation were also analyzed. At Jackson all of the selected climatic factors were highly correlated with ET. These correlations at Knoxville were somewhat lower than those at Jackson, but they were highly significant, nevertheless. The correlations of the ET from the treatments with open pan evaporation were highly significant in every case, with very little difference in the regression equations of the various treatments.

Water use was summarized into nine 14-day periods to include the corn growing season. For the first period the water use was low as the plants were emerging from the soil. Water use increased gradually during the next two periods as the corn plant developed in size. For the next four periods water use was at its highest as the corn was tasseling, silking and developing the kernels. After this time of peak water use, a gradual decrease in water use was noted for the last two periods as the corn matured and the kernels dried. The peak water use for the five year average was 0.22 inches per day at both locations.

This peak occurred during the fifth 14-day period at Knoxville and during the fourth and sixth 14-day period at Jackson.

The extensive records of water use made possible several comparisons of the ET rates from the various treatments. For the five year average, the irrigated plots used 3.8 and 2.0 more inches of water than the unirrigated plots at Knoxville and Jackson, respectively. There was no significant difference in water use which could be attributed to nitrogen levels. During the year of the highest rainfall at each location, the ET on the unirrigated plots was appreciably higher than during the other years. The plots receiving no nitrogen and no irrigation used the least amount of water as was expected.

The use of nitrogen fertilizer increased the yield for rates up to 120 pounds per acre at Knoxville and up to 180 pounds per acre at Jackson. In addition to increasing yields, nitrogen fertilization increased the water use efficiency. There was a considerable increase in water use efficiency as the nitrogen rate was increased from 0 to 120 pounds per acre but higher nitrogen rates gave only a slight increase in water use efficiency.

As expected, the response to irrigation was conditioned by the weather which prevailed during the different growing seasons. During the wetter seasons no significant yield increases due to irrigation were observed but during the dry seasons of 1962 and 1966 at Jackson, and 1964 at Knoxville, there were significant yield increases due to irrigation. When the average yield for all years for the three moisture levels was analyzed, a significant yield increase due to irrigation was found at both locations.

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TABLE A-1

SOME PHYSICAL CHARACTERISTICS OF MEMPHIS AND SEQUATCHIE SOILS

Soil	Depth of Sample (in.)	Organic Matter (Per-cent)	Bulk Density	Particle Density	Sand (Per-cent)	Silt (Per-cent)	Clay (Per-cent)	Percent Large Pore Space*	Percent Small Pore Space	1/3 Bar Water (Percent by vol.)	15 Bar Water (Percent by vol.)
Memphis Silt Loam	0-6	1.1	1.40	2.66	12.0	72.0	16.0	13.8	29.2	32.4	7.1
	6-12	1.1	1.48	2.65	11.2	70.8	18.0	9.9	30.2	36.0	8.0
Sequatchie Fine Sandy Loam	0-6	1.6	1.53	2.65	70.5	18.6	10.8	22.1	28.3	26.6	9.9
	6-12	1.0	1.51	2.63	70.3	17.9	12.8	16.0	29.0	27.0	10.9

*Pores which drain under 50 cm tension.

TABLE A-2

MEASURED EVAPOTRANSPIRATION FOR SELECTED TREATMENTS IN CORN ON SEQUATCHIE FINE SANDY LOAM AT KNOXVILLE DURING 1967

Period Number	From	To	No Irrigation Mean/ Day	No Irrigation Cumu- lated	2 Atm. Tension Mean/ Day	2 Atm. Tension Cumu- lated	0 lb. N/A Mean/ Day	0 lb. N/A Cumu- lated	120 lb. N/A Mean/ Day	120 lb. N/A Cumu- lated	300 lb. N/A Mean/ Day	300 lb. N/A Cumu- lated	Average of All Treatments Mean/ Day	Average of All Treatments Cumu- lated
			Evapotranspiration in Acre Inches											
1	5/11	5/24	.14	1.96	.14	1.96	.14	1.96	.14	1.96	.14	1.96	.14	1.96
2	5/25	6/7	.18	4.48	.19	4.62	.18	4.48	.19	4.62	.18	4.48	.18	4.47
3	6/8	6/21	.22	7.56	.26	8.62	.22	7.56	.25	8.12	.23	7.24	.23	7.70
4	6/22	7/5	.21	10.50	.26	11.90	.27	11.34	.26	11.76	.27	11.02	.26	11.34
5	7/6	7/19	.26	14.14	.33	16.52	.28	15.28	.31	16.10	.31	15.36	.30	15.54
6	7/20	8/2	.24	17.50	.19	19.18	.19	17.92	.23	19.32	.20	18.16	.21	18.48
7	8/3	8/16	.18	20.02	.21	22.12	.19	20.58	.20	22.12	.22	21.24	.20	21.28
8	8/17	8/30	.11	21.56	.12	23.80	.11	22.12	.11	23.66	.11	22.78	.11	22.82
9	8/31	9/13	.14	23.52	.15	25.90	.13	23.94	.16	25.90	.12	24.46	.14	24.78
Total	5/11	9/13		23.52		25.90		23.94		25.90		24.46		24.78

TABLE A-3

MEASURED EVAPOTRANSPIRATION IN CORN UNDER DIFFERENT MOISTURE AND NITROGEN LEVELS ON SEQUATCHIE FINE SANDY LOAM AT KNOXVILLE DURING 1967

			No Irrigation						5 Atmospheres Tension						2 Atmospheres Tension					
			0 lb. N/A		120 lb. N/A		300 lb. N/A		0 lb. N/A		120 lb. N/A		300 lb. N/A		0 lb. N/A		120 lb. N/A		300 lb. N/A	
Period Number	From	To	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated
			Evapotranspiration in Acre Inches																	
1	5/11	5/24	.14	1.96	.14	1.96	.14	1.96	.14	1.96	.14	1.96	.14	1.96	.14	1.96	.14	1.96	.14	1.96
2	5/25	6/7	.18	4.48	.18	4.48	.17	4.34	.18	4.48	.19	4.62	.18	4.48	.19	4.62	.20	4.76	.19	4.62
3	6/8	6/21	.20	7.28	.23	7.70	.23	7.56	.24	7.84	.20	7.42	.22	7.56	.22	7.70	.28	8.68	.23	7.84
4	6/22	7/5	.21	10.22	.21	10.64	.21	10.50	.34	12.60	.32	11.90	.31	11.90	.26	11.34	.25	12.18	.28	11.76
5	7/6	7/19	.26	13.86	.27	14.42	.25	14.00	.28	16.52	.34	16.66	.36	16.94	.31	15.68	.32	16.66	.31	16.10
6	7/20	8/2	.21	16.80	.25	17.92	.27	17.78	.19	19.18	.21	19.60	.17	19.32	.18	18.20	.23	19.88	.17	18.48
7	8/3	8/16	.18	19.32	.17	20.30	.18	20.30	.20	21.98	.22	22.68	.25	22.82	.19	20.86	.21	22.82	.22	21.56
8	8/17	8/30	.11	20.86	.11	21.84	.11	21.84	.12	23.66	.11	24.22	.09	24.08	.10	22.26	.11	24.36	.14	23.52
9	8/31	9/13	.14	22.82	.14	23.80	.13	23.66	.13	25.48	.14	26.18	.11	25.62	.13	24.08	.19	27.02	.12	25.20
Total	5/11	9/13		22.82		23.80		23.66		25.48		26.18		25.62		24.08		27.02		25.20

TABLE A-4

AIR MOVEMENT, OPEN PAN EVAPORATION AND TEMPERATURES RECORDED AT THE PLANT SCIENCE FARM, KNOXVILLE, DURING 1967

			Air Movement (miles)		Open Pan Evaporation (inches)		Temperatures (°F)					
							Maximum		Minimum		Mean	
Period Number	From	To	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated
1	5/11	5/24	54.5	763	.18	2.45	73.4	1028	49.7	696	61.3	858
2	5/25	6/7	41.0	1337	.20	5.21	80.4	2154	57.1	1495	68.7	1820
3	6/8	6/21	20.9	1630	.24	8.60	87.5	3379	61.7	2359	74.6	2864
4	6/22	7/5	35.1	2122	.20	11.41	84.2	4558	62.9	3240	73.6	3894
5	7/6	7/19	27.0	2500	.17	13.79	80.3	5682	60.7	4090	70.5	4881
6	7/20	8/2	25.5	2857	.17	16.20	84.8	6870	64.8	4998	74.8	5929
7	8/3	8/16	26.5	3228	.21	19.10	84.4	8051	61.2	5854	72.7	6948
8	8/17	8/30	24.3	3568	.14	21.04	82.6	9207	64.3	6754	73.4	7976
9	8/31	9/13	23.3	3894	.15	23.08	78.6	10309	56.2	7541	67.4	8920
Total	5/11	9/13		3894		23.08		10309		7541		8920

TABLE A-5

SUNSHINE HOURS, TOTAL SOLAR RADIATION, DEGREE-SUNSHINE HOURS, AND RAINFALL RECORDED AT THE PLANT SCIENCE FARM, KNOXVILLE, DURING 1967

Period Number	From	To	Sunshine Hours		Total Solar Radiation g. cal./cm.^{2}		Degree-Sunshine Hours		Rain-fall inches
			Mean/ Day	Cumulated	Mean/ Day	Cumulated	Mean/ Day	Cumulated	
1	5/11	5/24	6.7	93.9	458.2	6415.6	411.0	5756.1	3.39
2	5/25	6/7	7.6	200.6	504.3	13475.5	522.1	13086.2	2.67
3	6/8	6/21	8.7	322.8	626.7	22249.1	649.0	22202.3	.19
4	6/22	7/5	6.9	419.0	511.2	29405.2	507.8	29282.6	3.20
5	7/6	7/19	6.3	507.4	436.2	35512.6	444.2	35514.8	5.04
6	7/20	8/2	7.2	608.8	462.2	41983.1	538.6	43099.5	4.17
7	8/3	8/16	8.8	732.2	553.7	49735.5	639.8	52070.7	.14
8	8/17	8/30	6.4	821.5	436.7	55849.8	469.8	58625.3	2.86
9	8/31	9/13	6.8	916.4	431.3	61888.6	458.3	65021.6	.60
Total	5/11	9/13		916.4		61888.6		65021.6	22.26

TABLE A-6

MEASURED EVAPOTRANSPIRATION FOR SELECTED TREATMENTS IN CORN ON MEMPHIS SILT LOAM AT JACKSON DURING 1966

Period Number	From	To	No Irrigation Mean/ Day	No Irrigation Cumu- lated	2 Atm. Tension Mean/ Day	2 Atm. Tension Cumu- lated	0 lb. N/A Mean/ Day	0 lb. N/A Cumu- lated	120 lb. N/A Mean/ Day	120 lb. N/A Cumu- lated	300 lb. N/A Mean/ Day	300 lb. N/A Cumu- lated	Average of All Treatments Mean/ Day	Average of All Treatments Cumu- lated
			Evapotranspiration in Acre Inches											
1	5/10	5/23	.08	1.12	.08	1.12	.08	1.12	.09	1.26	.08	1.12	.08	1.12
2	5/24	6/6	.08	2.24	.08	2.24	.08	2.24	.09	2.52	.08	2.24	.08	2.24
3	6/7	6/20	.12	3.92	.24	5.60	.15	4.34	.19	5.18	.16	4.48	.17	4.62
4	6/21	7/4	.24	7.28	.26	9.24	.26	7.98	.25	8.68	.23	7.70	.24	7.98
5	7/5	7/18	.23	10.50	.26	12.88	.25	11.48	.24	12.04	.23	10.92	.24	11.34
6	7/19	8/1	.15	12.60	.24	16.24	.14	13.44	.24	15.40	.24	14.28	.21	14.28
7	8/2	8/15	.10	14.00	.14	18.20	.12	15.12	.12	17.08	.12	15.96	.12	15.96
8	8/16	8/29	.09	15.26	.13	20.02	.12	16.80	.11	18.62	.11	17.50	.12	17.64
9	8/30	9/12	.09	16.52	.13	21.84	.12	18.48	.11	20.16	.11	19.04	.11	19.18
Total	5/10	9/12		16.52		21.84		18.48		20.16		19.04		19.18

TABLE A-7

MEASURED EVAPOTRANSPIRATION IN CORN UNDER DIFFERENT MOISTURE AND NITROGEN LEVELS ON MEMPHIS SILT LOAM AT JACKSON DURING 1966

			No Irrigation						5 Atmospheres Tension						2 Atmospheres Tension					
			0 lb. N/A		120 lb. N/A		300 lb. N/A		0 lb. N/A		120 lb. N/A		300 lb. N/A		0 lb. N/A		120 lb. N/A		300 lb. N/A	
Period Number	From	To	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated	Mean/ Day	Cumu- lated
			Evapotranspiration in Acre Inches																	
1	5/10	5/23	.08	1.12	.08	1.12	.08	1.12	.08	1.12	.10	1.40	.08	1.12	.09	1.26	.08	1.12	.08	1.12
2	5/24	6/6	.08	2.24	.08	2.24	.08	2.24	.08	2.24	.10	2.80	.08	2.24	.09	2.52	.08	2.24	.08	2.24
3	6/7	6/20	.10	3.64	.15	4.34	.10	3.64	.12	3.94	.16	5.04	.14	4.20	.23	5.74	.26	5.88	.24	5.60
4	6/21	7/4	.24	7.00	.24	7.70	.24	7.00	.27	7.70	.23	8.26	.19	6.86	.26	9.38	.27	9.66	.26	9.24
5	7/5	7/18	.23	10.22	.22	10.78	.23	10.22	.27	11.48	.23	11.48	.19	9.52	.25	12.88	.27	13.44	.26	12.88
6	7/19	8/1	.08	11.34	.21	13.72	.17	12.60	.20	14.28	.25	14.98	.26	13.16	.15	14.98	.26	17.08	.30	17.08
7	8/2	8/15	.09	12.60	.09	14.98	.11	14.14	.12	15.96	.13	16.80	.12	14.84	.14	16.94	.14	19.04	.13	18.90
8	8/16	8/29	.09	13.86	.08	16.10	.11	15.68	.12	17.64	.12	18.48	.10	16.24	.14	18.90	.13	20.86	.11	20.44
9	8/30	9/12	.09	15.12	.08	17.22	.11	17.22	.12	19.32	.12	20.16	.10	17.64	.14	20.86	.13	22.86	.11	21.98
Total	5/10	9/12		15.12		17.22		17.22		19.32		20.16		17.64		20.86		22.86		21.98

TABLE A-8

AIR MOVEMENT, OPEN PAN EVAPORATION AND WATER LOSS FROM ATMOMETERS AT THE WEST TENNESSEE AGRICULTURAL EXPERIMENT STATION, JACKSON, DURING 1966

Period Number	From	To	Air Movement (miles) Mean/ Day	Cumu- lated	Open Pan Evaporation (inches) Mean/ Day	Cumu- lated	Atmometer Evaporation in ml. Mean/Day Black	White	B-W	Cumulated Black	White	B-W
1	5/10	5/23	63.8	893	.22	3.08	54.0	35.4	18.6	757	496	261
2	5/24	6/6	55.8	1675	.30	7.31	79.0	60.4	18.7	1864	1341	523
3	6/7	6/20	44.4	2296	.27	11.15	71.1	50.8	20.2	2859	2053	806
4	6/21	7/4	30.1	2718	.29	15.26	74.6	56.4	18.2	3903	2842	1061
5	7/5	7/18	31.6	3160	.30	19.47	67.4	47.0	20.4	4847	3500	1347
6	7/19	8/1	24.6	3504	.27	23.25	67.4	50.8	16.4	5791	4214	1577
7	8/2	8/15	28.2	3899	.20	26.04	47.0	32.9	14.0	6449	4675	1774
8	8/16	8/29	20.1	4181	.20	28.86	49.2	33.1	16.1	7138	5138	1999
9	8/30	9/12	23.6	4511	.17	31.25	43.7	32.7	11.0	7750	5596	2153
Total	5/10	9/12		4511		31.25				7750	5596	2153

TABLE A-9

TEMPERATURES, TOTAL SOLAR RADIATION AND RAINFALL AT THE WEST TENNESSEE AGRICULTURAL EXPERIMENT STATION, JACKSON, DURING 1966

Period Number	From	To	Temperatures (°F) Maximum Mean/Day	Temperatures (°F) Maximum Cumulated	Temperatures (°F) Minimum Mean/Day	Temperatures (°F) Minimum Cumulated	Temperatures (°F) Mean Mean/Day	Temperatures (°F) Mean Cumulated	Total Solar Radiation g. cal./cm.^{2} Mean/Day	Total Solar Radiation g. cal./cm.^{2} Cumulated	Rainfall inches
1	5/10	5/23	75.2	1054	54.5	763	64.8	908	448.6	6281	4.29
2	5/24	6/6	80.8	2185	56.3	1551	68.5	1866	566.5	14756	.73
3	6/7	6/20	85.1	3377	61.0	2405	73.5	2895	587.7	22985	.69
4	6/21	7/4	91.6	4659	64.7	3311	78.1	3989	559.9	30824	1.61
5	7/5	7/18	94.3	5979	72.1	4321	83.2	5154	546.4	38473	2.05
6	7/19	8/1	91.6	7261	68.7	5283	80.1	6276	554.6	46238	.56
7	8/2	8/15	85.8	8463	66.7	6217	76.3	7344	410.1	51880	3.01
8	8/16	8/29	84.4	9644	64.1	7114	74.2	8383	483.1	58643	.78
9	8/30	9/12	85.1	10836	63.8	8008	74.5	9426	317.6	63090	.50
Total	5/10	9/12		10836		8008		9426		63090	14.22

TABLE A-10

REGRESSION ANALYSIS OF ET WITH SELECTED CLIMATIC FACTORS ON A CUMULATIVE BASIS; FIRST 42-DAY PERIOD AT KNOXVILLE

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative ET					
X_1	Cumulative relative humidity percentage	.9610	.9235	0.00013	0.6168	Y = -0.961 + 0.0020X
X_2	Cumulative water loss from black atmometers in ml.	.9715	.9438	0.00015	0.5285	Y = -0.667 + 0.0035X
X_3	Cumulative water from white atmometers in ml.	.9653	.9318	0.00053	0.5830	Y = 0.103 + 0.0057X
X_4	Cumulative B-W in ml.	.9199	.8462	0.00067	0.8749	Y = -0.472 + 0.0077X
X_5	Cumulative maximum temperatures °F	.9630	.9274	0.00016	0.6011	Y = -0.448 + 0.0020X
X_6	Cumulative mean temperatures °F	.9689	.9388	0.00019	0.5525	Y = -0.377 + 0.0023X
X_7	Cumulative dew point temperatures °F	.9157	.8385	0.00054	0.8963	Y = 1.066 + 0.0025X
X_8	Cumulative solar radiation in g. cal./cm.^{2}	.9293	.8661	0.00004	0.8240	Y = -.370 + 0.0003X

TABLE A-11

REGRESSION ANALYSIS OF ET WITH SELECTED CLIMATIC FACTORS ON A CUMULATIVE BASIS; SECOND 42-DAY PERIOD AT KNOXVILLE

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative ET					
X_1	Cumulative relative humidity percentage	.9293	.8636	0.00019	0.9788	Y = -1.203 + 0.0022X
X_2	Cumulative water loss from black atmometers in ml.	.9786	.9576	0.00021	0.5458	Y = -2.510 + 0.0042X
X_3	Cumulative water loss from white atmometers in ml.	.8583	.7367	0.00063	1.3599	Y = 0.680 + 0.0055X
X_4	Cumulative B-W in ml.	.8498	.7222	0.00097	1.3970	Y = -3.971 + 0.0079X
X_5	Cumulative maximum temperatures °F	.8567	.7339	0.00044	1.3671	Y = -0.631 + 0.0021X
X_6	Cumulative mean temperatures °F	.8699	.7567	0.00031	1.3072	Y = -0.377 + 0.0023X
X_7	Cumulative dew point temperatures °F	.7174	.5147	0.00092	1.8463	Y = 1.207 + 0.0018X
X_8	Cumulative solar radiation in g. cal./cm.^{2}	.7656	.5854	0.00009	1.7050	Y = 1.534 + 0.0003X

TABLE A-12

REGRESSION ANALYSIS OF ET WITH SELECTED CLIMATIC FACTORS ON A CUMULATIVE BASIS; LAST 42-DAY PERIOD AT KNOXVILLE

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative ET					
X_1	Cumulative relative humidity percentage	.9457	.8943	0.00017	0.6861	Y = 1.011 + 0.0018X
X_2	Cumulative water loss from black atmometers in ml.	.8351	.6974	0.00041	1.1614	Y = 7.333 + 0.0026X
X_3	Cumulative water loss from white atmometers in ml.	.6439	.4146	0.00089	1.6154	Y = 8.912 + 0.0024X
X_4	Cumulative B-W in ml.	.6549	.4289	0.00106	1.5955	Y = 6.670 + 0.0043X
X_5	Cumulative maximum temperatures °F	.8457	.7152	0.00036	1.1268	Y = 2.631 + 0.0017X
X_6	Cumulative mean temperatures °F	.8654	.7489	0.00025	1.0578	Y = 1.066 + 0.0019X
X_7	Cumulative dew point temperatures °F	.5680*	.3226	0.00091	1.7376	Y = 3.027 + 0.0010X
X_8	Cumulative solar radiation in g. cal./cm.^{2}	.7130	.5081	0.00006	1.4804	Y = 8.503 + 0.0002X

*Correlation not significant at 0.05 level.

TABLE A-13

REGRESSION ANALYSIS OF ET WITH SELECTED CLIMATIC FACTORS ON A CUMULATIVE BASIS; FIRST 42-DAY PERIOD AT JACKSON

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative ET					
X_1	Cumulative relative humidity percentage	.9690	.9389	0.00011	0.4781	Y = -1.160 + 0.0019X
X_2	Cumulative water loss from black atmometers in ml.	.9214	.8490	0.00024	0.7301	Y = -0.265 + 0.0021X
X_3	Cumulative water loss from white atmometers in ml.	.8822	.7783	0.00041	0.8846	Y = 0.441 + 0.0028X
X_4	Cumulative B-W in ml.	.8948	.8007	0.00085	0.8388	Y = -0.149 + 0.0061X
X_5	Cumulative maximum temperatures °F	.9505	.9034	0.00016	0.5839	Y = -0.500 + 0.0017X
X_6	Cumulative mean temperatures °F	.9558	.9136	0.00017	0.5521	Y = -0.499 + 0.0020X
X_7	Cumulative dew point temperatures °F	.9505	.9034	0.00016	0.6010	Y = -0.951 + 0.0022X
X_8	Cumulative solar radiation in g. cal./$cm.^2$	.8556	.7320	0.00004	0.9887	Y = 0.209 + 0.0002X

TABLE A-14

REGRESSION ANALYSIS OF ET WITH SELECTED CLIMATIC FACTORS ON A CUMULATIVE BASIS; SECOND 42-DAY PERIOD AT JACKSON

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative ET					
X_1	Cumulative relative humidity percentage	.9395	.8827	0.00021	0.9559	Y = -1.980 + 0.0025X
X_2	Cumulative water loss from black atmometers in ml.	.7610	.5791	0.00073	1.8196	Y = -0.268 + 0.0027X
X_3	Cumulative water loss from white atmometers in ml.	.5873	.3449	0.00110	2.2701	Y = 0.5873 + 0.0025X
X_4	Cumulative B-W in ml.	.9646	.9304	0.00104	0.7395	Y = -5.146 + 0.0121X
X_5	Cumulative maximum temperatures °F	.9674	.9359	0.00020	0.7108	Y = -2.557 + 0.0024X
X_6	Cumulative mean temperatures °F	.9717	.9442	0.00021	0.6621	Y = -2.450 + 0.0027X
X_7	Cumulative dew point temperatures °F	.9583	.9183	0.00019	0.7968	Y = -1.951 + 0.0032X
X_8	Cumulative solar radiation in g. cal./cm.^{2}	.5584*	.3101	0.00008	2.3268	Y = 5.986 + 0.0002X

*Correlation not significant at 0.05 level.

TABLE A-15

REGRESSION ANALYSIS OF ET WITH SELECTED CLIMATIC FACTORS ON A CUMULATIVE BASIS; LAST 42-DAY PERIOD AT JACKSON

	Variables	Coefficients of Correlation	r^2 or R^2	Standard Error of Regression Coefficient	Standard Error of Estimate	Equation Describing the Relationship
Y	Cumulative ET					
X_1	Cumulative relative humidity percentage	.7062	.4987	0.00051	1.5111	Y = 4.160 + 0.0014X
X_2	Cumulative water loss from black atmometers in ml.	.3158*	.0997	0.00084	2.1122	Y = 13.043 + 0.0009X
X_3	Cumulative water loss from white atmometers in ml.	.3029*	.0917	0.00106	2.2249	Y = 18.550 + 0.0001X
X_4	Cumulative B-W in ml.	.7209	.5196	0.00232	1.5429	Y = 3.358 + 0.0076X
X_5	Cumulative maximum temperatures °F	.6356	.4040	0.00049	1.7186	Y = 6.773 + 0.0013X
X_6	Cumulative mean temperatures °F	.6841	.4680	0.00053	1.6237	Y = 5.745 + 0.0016X
X_7	Cumulative dew point temperatures °F	.7710	.5944	0.00037	1.3593	Y = 5.660 + 0.0019X
X_8	Cumulative solar radiation in g. cal./cm.^{2}	.1861*	.0344	0.00006	2.1872	Y = 21.072 + 0.0004X

*Correlation not significant at 0.05 level.

VITA

David E. McKinney was born on October 24, 1940, in Roane County, Tennessee, and attended the public schools there. Following high school, he served in the U.S. Navy for three years. After his discharge, he completed his B.S. in Agronomy at Tennessee Technological University. He worked for the Soil Conservation Service for eighteen months before returning to The University of Tennessee to work on his Master's degree in Agronomy.