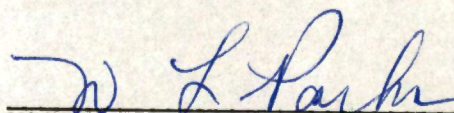


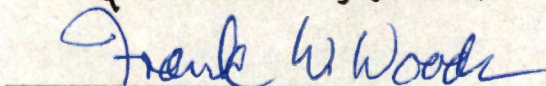
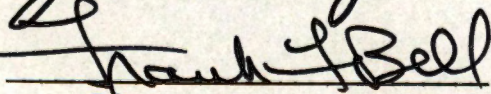
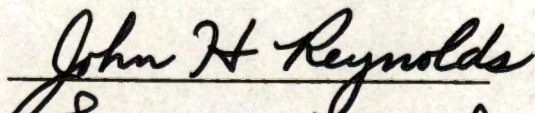
To the Graduate Council:

I am submitting herewith a dissertation written by John Marcus Safley, Jr., entitled "Comparison of Methods for Estimation of Drought Intensity and the Relationship of Drought to Yields of Agronomic Crops in Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

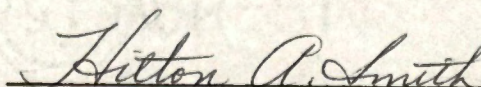


William L. Parks, Major Professor

We have read this dissertation
and recommend its acceptance:



Accepted for the Council:



Vice Chancellor
Graduate Studies and Research

COMPARISON OF METHODS FOR ESTIMATION OF DROUGHT INTENSITY
AND THE RELATIONSHIP OF DROUGHT TO YIELDS OF
AGRONOMIC CROPS IN TENNESSEE

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee

John Marcus Safley, Jr.

August 1974

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ABSTRACT

Delineation of the general effects of drought on crops in Tennessee and the critical periods during which crop yields are significantly affected had not been performed for Tennessee. Purposes of this study were:

1. To calculate drought-days using evapotranspiration values derived from four water-use models;
2. To evaluate each model by application to variety trial yields of corn, cotton, and burley tobacco varieties from several locations in the state;
3. To select the best model for use under Tennessee conditions and to calculate drought probabilities from those data; and
4. To evaluate county yield estimates in terms of their response to drought-days as calculated by the best model.

Evapotranspiration values were calculated using the methods described by Penman, Blaney-Criddle, and Thornthwaite; drought-days were calculated using these values and were summed by climatic weeks and by calendar months. An adjusted Thornthwaite method developed by Wiser and van Schilfgaarde which only calculated drought-days on a monthly basis was also evaluated.

Crop yield variation proved to be most sensitive to drought calculated using Thornthwaite-derived evapotranspiration values. Crop response to Blaney-Criddle-derived drought was intermediate, while the

yield variation response to Penman-derived values indicated that the latter method was least sensitive to prevailing conditions. Drought totals per month as calculated by the Wiser modification as well as monthly totals from the Thornthwaite equation proved to be less sensitive to actual conditions as reflected in crop yield than did weekly totals of drought-days. This was primarily due to the masking of within-month variation of moisture status which was more precisely revealed by weekly drought-day totals. Relative lack of predictive power of Penman-derived drought totals was attributed to the complexity of the formula and the lack of truly adequate data from many locations within Tennessee. Regressions of weekly drought-day totals against variety trial yields indicated that critical periods for corn growth occurred primarily during germination, during anthesis, and during grain-filling. Weekly periods critical for cotton yield were approximately the same for all West Tennessee locations; however, moisture stress was more significant at Fort Pillow and Ames Plantation than at Jackson or Knoxville. Tobacco yields varied with significant deficits occurring from the first of July through August. In general, for all crops, stress at almost any stage between floral initiation and maturity was likely to result in yield variation. At those general levels of available water within the effective rooting zone it appeared that the preflowering stage was the most tolerant to moisture deficit; however, drought at flowering and during maturation were the primary causes of yield reduction and/or variation.

Probabilities of drought occurrence were calculated using Thornthwaite ET values for each of the 50 selected locations.

Analyses of county yield estimates indicated that moisture status does play a role in production; however, due to extreme linearity of these yield estimates and to the nature of their derivation no further interpretation was considered appropriate.

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CHAPTER I

INTRODUCTION

An understanding of natural conditions which affect soil water regime and the response of plants to that status is needed to guide efficient water management for crops. Irrigation experiments provide information on adequate soil moisture levels for profitable crop response; however, these efforts must be supported by knowledge of general soil moisture conditions through time in the area where irrigation decisions are made. Moisture deficit conditions must be described in terms of relative frequency of occurrence and how that occurrence is related to the responses of crop and soil. Soil moisture conditions are intimately related to plant processes of germination, growth, flowering, and fruit set as well as to human activities related to crop production during the planting period, growing season, and the time of harvest. In this work special attention has been given to the growing season for purposes of evaluating water-use models in relation to crop yields.

The objectives of this research were to (1) evaluate several water-use models in terms of how Tennessee crops respond to moisture deficits calculated from each model, (2) ascertain the best model and describe critical periods of moisture status for several crops, and (3) calculate the probabilities of drought occurrence for several locations within Tennessee using the most acceptable model. Probabilities will not be

reported here; however, they will appear in a University of Tennessee Agricultural Experiment Station bulletin (32).



CHAPTER II

LITERATURE REVIEW

A knowledge of the relationships which exist between soil moisture and crop response is necessary to more completely understand optimum conditions of plant growth. Moisture excesses as well as deficits contribute to production variation; however, the significance of deficit in production is the objective of this investigation.

I. AGRICULTURAL DROUGHT

Drought has been variously defined to fit the concepts of water use and/or soil deficit of individual researchers. Christidis and Harrison (10) made the distinction between atmospheric drought, caused by hot, dry winds, producing mostly temporary wilting, and soil drought which usually produces permanent wilting or other plant injury. Barger and Thom (1) defined drought as a specific period of time during which the total amount of rainfall was deficient to the extent that yields fell below normal for the area. Drought in the southern United States was believed to occur whenever any two-week period received less than .25 inch of rainfall (8). Strommen, Van den Brink, and Ridder (38) stated drought to be any amount of precipitation less than normal for a given area.

To quantify drought for purposes of analysis one of the more useful concepts is that of the drought-day. Van Bavel (41) observed that

agricultural drought should be defined on the basis of available soil water conditions and subsequent plant behavior. He postulated the concept of a drought-day as a 24-hour period (beginning at the time at which the precipitation of the previous day was recorded) in which the soil moisture stress exceeds a limit, based on experimental research, at which photosynthetic processes of a crop are depressed. As a measure of drought a drought-day occurred whenever available soil moisture was depleted to a point critical for normal plant processes, as estimated from precipitation and evapotranspiration data by a moisture balance method. This concept has acquired widespread use in that it is relatively easy to quantify occurrence and duration by this method. Calculation of drought occurrence has been performed for several states and regions using this approach (19,42,43,44,45,48).

Rainfall has four fates: (1) surface runoff; (2) evaporation from soil and/or plant surfaces; (3) transpiration; (4) percolation (4). Of these, only evaporation and transpiration comprise water losses which are primarily related to plant growth. Evapotranspiration (ET), or consumptive-use (4) as it is sometimes called, is the loss of water from a unit area during a specified time by evaporation from the soil or plant surface and by transpiration from plants (7). Briggs and Schantz (6), Blaney (4), and Kelley (17) have reported values of consumptive use of water by plants. Water requirement was defined as the ratio of the weight of water absorbed by a plant to the weight of the aboveground, dry matter production.

The tension with which soil moisture is held determines its availability to plants. Although different stresses occur simultaneously throughout the root zone it is advantageous to examine the entire root zone. In general it has been observed that transpiration losses decrease as soil moisture is depleted (39).

Thornthwaite (40) developed the concept of potential evapotranspiration and defines it as the water loss from a moist soil tract completely covered by vegetation and large enough to prevent an oasis effect. Penman (29) defines potential evapotranspiration as the amount of water transpired per unit time by a short, green crop which completely shades the ground, is of uniform height, and never experiences water shortage.

II. EMPIRICAL FORMULAE FOR ESTIMATING EVAPOTRANSPIRATION

Thornthwaite (40) derived an empirical formula for estimating PE from his research in the eastern United States. The formula can be expressed as

$$PE = 1.6 (10T/I)^a$$

where PE is the unadjusted evapotranspiration total expressed in centimeters for a month of 30 days, T is the mean monthly temperature in degrees Celsius, I is the annual heat index, and a is a location-specific constant. The annual heat index, I, is the sum of 12 monthly heat indices, where $i = (T/5)^{1.514}$. The location-specific constant is equal to $0.49239 + 0.01792I + 0.0000771I^2 - 0.000000675I^3$. By using corrected

daylength per month the adjusted PE can be calculated. The relationships described here are valid only when mean air temperature is between 0° and 26.5°C . Evapotranspiration is assumed to be zero at lower temperatures. The rate is considered to increase monotonically at higher temperatures independent of the heat index I (33). Thornthwaite justified his exclusion of climatic factors other than temperature by stating that those factors vary significantly with temperature. One major disadvantage to this method is that application of it outside of relatively humid climate is not advised due to a seasonal lag of ET behind temperature (24).

Palmer and Havens (26) have developed nomograms for determination of ET and PE in accordance with the general equations of Thornthwaite.

Penman (29) combined the aerodynamic and energy budget approaches to derive an expression with which to approximate evaporative loss from an open water surface. He combined an aerodynamic factor to account for turbulent transport of vapor by eddy diffusion and an energy factor to account for evaporative degradation of incoming radiation. The use of a corrective factor is required to adjust calculated loss to evapotranspirative loss. G. W. Smalley (personal communication) has expressed the equation in expanded form for clarity. It appears as

$$\begin{aligned} \text{PE} = & \left(\frac{\Delta}{\Delta + \delta} \right) R_a (1 - r) (.18 + .55n/N) \\ & - \left(\frac{\Delta}{\Delta + \delta} \right) \sigma T^4 (.56 - 0.092 \sqrt{VP}) (.10 + .90n/N) \\ & + \left(\frac{\delta}{\Delta + \delta} \right) .35 (1. + W/100) (SVP - VP) \end{aligned}$$

in millimeters evaporation per day, where:

Δ = slope of the saturation vapor pressure curve at mean air temperature in millibars per degrees C;

δ = constant of the wet and dry bulb psychrometer equation;

R_a = Angot's value (the theoretical incoming shortwave radiation at the outer limits of the atmosphere);

r = albedo;

n = actual hours of sunshine;

N = theoretical duration of sunshine;

σT^4 = black body radiation at mean temperature (T) in degrees Kelvin;

VP = mean vapor pressure at mean air temperature;

SVP = saturation vapor pressure at mean air temperature; and

W = run of wind at standard height of 2 meters (miles per day).

Penman's formula requires data for radiation, humidity, temperature, and wind which are usually available only from first-order weather stations (9). Two disadvantages are inherent in the Penman equation other than the difficulty of acquiring all needed data. These difficulties are: (1) the conversion of calculated PE to ET over vegetation is difficult to precisely calculate; and (2) unless modified, the equation describes only those areas where optimum water supply is maintained (24).

Blaney and Criddle (5) developed a formula for calculating consumptive-use of water which has had wide use in the more arid portions of the United States. They related mean monthly air temperature in $^{\circ}\text{F}$ to monthly percent of yearly daytime hours, together with a crop coefficient, to evaluate consumptive use (U) in inches per month. The

can be written as

$$U = KTp$$

where K is a crop water use coefficient, T is monthly daytime temperature in °F, and p is the monthly percent of yearly daytime hours. Consumption coefficients were developed from field and lysimeter studies. This method does have the advantages that it is easy to use and that the necessary data are available from weather records. However, several assumptions are made with regard to the equation: (1) there is non-limiting water supply to the plants; (2) consumptive use varies directly with daytime hour percent and monthly mean temperature; (3) fertility does not vary among areas; and (4) length of the growing season is an index to consumptive use (24).

Wiser and van Schilfgaarde (49) have developed a water balance method for estimation of soil moisture status which involves modifications of Thornthwaite's 1948 method of calculating PE. Their procedure involves correcting the values derived for actual daylength by allowing for latitudinal effects. The major alteration is in the soil moisture they use. The solum is considered to be composed of layers with different holding capacities and depletion rates. The key assumption is that moisture supplied by precipitation moves down through the soil layers only if the layer above the layer of percolation is at field capacity. Daily ET is obtained from PE by correcting for soil moisture using the relation:

$$ET = PE (SMC_{t-1}^* / MSC^*)$$

where SMC^*_{t-1} is the soil moisture status of the uppermost layer at the end of the previous day and MSC^* is the total storage capacity of this same layer.

III. CROP RESPONSES TO DROUGHT STRESS

Wadleigh (46) commented that as the soil dries toward the permanent wilting percentage there is little increase in moisture tension until over two-thirds of the available water has been used. However, the moisture tension increases greatly as the soil continues to dry toward the permanent wilting percent. He concluded that plant growth can be severely retarded after depletion of greater than two-thirds of the available water.

Russell and Danielson (31) reported that mature corn (Zea mays L.) used water to a depth of 1.5 meter or more on a deep permeable, well drained soil. Bennett et al. (3) found that pearl millet (Pennisetum typhoides (Burm.) Stapf & C. E. Hubb), sudangrass (Sorghum bicolor), and sorghum (Sorghum spp.) extract moisture primarily from the top 61 cm of soil between emergence and the time they achieved a height of 30 cm. Extraction depth increased with growth to a depth of 122 cm by harvest.

Species with determinant flowering can have yields reduced considerably by a short period of moisture stress during flowering; the same period will have only moderate effect on indeterminate species such as cotton (Gossypium hirsutum L.) and soybeans (Glycine max L.) (34).

Robins and Domingo (30) reported that corn grain yield was reduced

22 percent by soil moisture depletion to the wilting point for periods of one to two days during tasseling. Longer periods of depletion reduced yields as much as 50 percent. Total seasonal rainfall at Wooster, Massachusetts was not correlated with corn yield; however, the distribution of rainfall was. Soil moisture status prior to silking was critical for yield increases (11).

McKinney (22) summarized water use into nine 14-day periods to include the corn growing season. Water use gradually increased during the first three periods as the plants germinated and grew. Water use for the next four periods was greatest; during that time the corn was tasseling, silking, and developing kernels. Use decreased over the last two periods. Kiesselbach (18) found correlations of corn yield to mean season free water evaporation equal to -0.792. Crop use efficiency was directly related to fertilization (22,27,28). Denmead and Shaw (12) observed that application of moisture stress to the wilting point prior to silking reduced corn grain yield by 25 percent; stress at silking stage reduced yield by 50 percent. When the same stress was applied after anthesis the yields were reduced by 21 percent. Odell (25) examined corn yield variation explained by rainfall and temperature between May 20 and August 23. Moisture effects were greater than temperature effects. From 36 days prior to full tassel to 14 days after, temperature and moisture accounted for 66.9 percent of yield variation. When technologically induced trend was included the percentage increased to 75. Letey and Peters (20) found corn yields inversely correlated with soil moisture stress. Yields depended on both

precipitation pattern and temperature. Parks and Knetsch (28) related drought intensity during three stages of growth to yield of Starr pearl-millet. They accounted for 94.8 percent of variation in yield by soil moisture status. Drought-days were most prevalent between June and early September in their study. Barger and Thom (2) investigated corn yields in Iowa during the period from mid-May to early September. Rainfall deficits were correlated significantly at the 0.1 level for all years of study. For drought years, deficits accounted for 25 to 60 percent of yield depression. Shaw, Runkles, and Barger (34) observed highest correlations between corn yield and water use during the period June 15 to August 1 in Iowa. Average daily water use during this period for the years 1954, 1955, and 1956 was 4.6, 4.6, and 3.8 mm respectively. Parks and Knetsch (27) used drought indices calculated by weighting drought-days to examine moisture stress effects on corn yields. Using drought indices and nitrogen application they accounted for 97 percent of variation among the 15 replicate means. Moisture stress during tasseling was an important source of yield variation. Wallace (47) correlated corn yields in Kansas for the years 1891 to 1919 with temperature and rainfall. He found these factors to be significantly correlated with yields in the months of June, July, and August; rainfall exhibited the largest correlations.

Dunlap (14) observed that wilting of cotton for three consecutive days caused appreciable reduction of boll weight. Squares and young bolls abscised as a result of moisture stress. Shedding was slight early in the season but did increase as the season progressed. In

eastern Arkansas a high correlation between cotton lint yield and rainfall for the months of April, May, and July was calculated. Amount of rain was not as important as was distribution (23).

Howe and Rhoades (16) reported that moisture stress prior to and during anthesis decreased corn grain yields, as did a dry period from silking to full maturity. Without irrigation corn used water from a greater depth than did irrigated corn. Nonirrigated corn produced 6.7 bushels per inch of water; irrigated corn produced from 7.0 to 9.2 bushels per inch of water.

CHAPTER III

MATERIALS AND METHODS

I. WEATHER DATA

Long-term climatic data used in evaluation of drought occurrence in Tennessee were obtained from daily observations made by National Weather Service first-order stations and Climatological Cooperative Stations, and at Tennessee Agricultural Experiment Station research units, branch stations, and field stations. Daily observations can include 24-hour precipitation accumulation, maximum and minimum air temperatures for the period, and air temperature at the time readings are made. First-order stations also record wind run, relative humidity, and solar radiation. Although precipitation data are available for all stations, both temperature and precipitation data are available for only 50 of the 65 stations in Tennessee (Table I).

The 50 stations were selected to create a sampling density of about one station for each two counties. They were chosen to give an even coverage of the physiographic regions of Tennessee, although it is realized that data obtained at each station is only representative of its immediate vicinity.

Stations were also evaluated as to their length of uninterrupted record. Thirty years of record was the desired length; however, in a few cases stations with longer periods of service were available. In

TABLE I
PERIOD OF RECORD AND LATITUDE FOR 50 STATIONS

Location	Period of Record	Total Years	Latitude	
			Degrees	Minutes
Allardt	1928-1970	43	36	23
Ashwood	1900-1970	71	35	35
Bolivar	1948-1970	23	35	16
Brownsville	1948-1970	23	35	36
Carthage	1931-1970	40	36	16
Celina	1948-1970	23	36	32
Chattanooga	1928-1970	43	35	02
Clarksville	1931-1970	40	36	33
Copperhill	1931-1970	40	35	00
Covington	1928-1970	43	35	34
Crossville	1912-1970	59	36	01
Dickson	1948-1970	23	36	04
Dover	1928-1970	43	36	23
Fayetteville	1948-1970	23	35	10
Franklin, Ky.	1928-1970	43	36	43
Franklin	1928-1970	43	35	56
Gatlinburg	1928-1970	43	35	41
Greeneville	1949-1970	22	36	06
Huntingdon	1949-1970	22	36	00
Jackson	1900-1970	71	35	37
Jefferson City	1948-1970	23	36	07
Kingsport	1931-1970	40	36	31
Knoxville Airport	1910-1970	61	35	49
Knoxville	1951-1970	20	35	57
Lewisburg	1928-1970	43	35	27
Loudon	1928-1962	35	35	44
Lynnville	1928-1970	43	35	20
Martin	1936-1970	35	36	21
Memphis Airport	1940-1970	31	35	03
Memphis	1928-1965	38	35	09
Middlesboro, Ky.	1928-1970	43	36	37
Milan	1930-1970	41	35	56
Monteagle	1938-1970	33	35	15
Moscow	1948-1970	23	35	04
Murfreesboro	1931-1970	40	35	55
Nashville	1948-1970	23	36	07
Neptune	1936-1970	35	36	19
Newbern	1948-1970	23	36	07
Newport	1927-1970	44	35	59
Oak Ridge	1948-1970	23	35	56

TABLE I (continued)

Location	Period of Record	Total Years	Latitude	
			Degrees	Minutes
Palmetto	1927-1970	44	35	29
Paris	1937-1970	34	36	19
Rogersville	1927-1970	44	36	25
Samburg	1942-1970	29	36	23
Savannah	1927-1970	44	35	14
Selmer	1948-1970	23	35	16
Sparta	1948-1970	23	35	57
Springfield	1942-1969	28	36	28
Tulahoma	1928-1970	43	35	22
Waynesboro	1948-1970	23	35	18

some cases, stations with lengths of record less than 30 years were chosen to maintain sampling density where there were no data meeting the desired criteria. There were a few instances in which a station closed after many years of operation and a new station was established in the vicinity. For purposes of calculation these station pairs were combined, thereby making possible evaluation of a longer record which reflected conditions in the area around both stations.

Within the data records of some stations there were missing observations ranging in duration from one day to several months. In the weekly calculations, a lack of one day per week was ignored; greater deficiencies led to deletion of the week from calculations. Likewise, if more than eight days were missing per month, then that month was deleted from monthly calculations. These instances occurred with varying frequency from year to year and among stations; therefore, calculations were made on unequal numbers of weeks and months for each site.

II. YIELD AND GROWTH DATA

Evaluation of long-term drought occurrence effects requires a crop yield data base of more than a few years duration. Yield data for corn, cotton, and burley tobacco were accumulated from certain of the nine Tennessee Agricultural Experiment Stations for the years 1947 to 1970.¹ In addition, county mean yield data for the crops were obtained

¹Data were taken from variety performance trial bulletins provided by Mr. C. R. Graves, Associate Professor of Plant and Soil Science, University of Tennessee, Knoxville.

from the Crop Reporting Service.² These data serve as a secondary source of data for drought evaluation. These yields are less than those in the variety trial program partly due to a less-than-optimum level of management.

Corn data are expressed in bushels per acre. Cotton yields are in pounds of lint per acre and tobacco data are in pounds of leaf per acre.

Because yields express a time trend which correlates with advancing technological inputs, the variation due to climatic effects can be masked. To correct for trend, yields were regressed against time to fit a linear trend to yields. Yield indices were computed as a ratio of actual to computed trend yields (37) thereby removing most trend effects. Indices range from a value of 0 to 2 and have an expected mean of unity and a variance that is homogeneous through time.

III. DROUGHT-DAY CALCULATION

Four water-use models were employed in drought-day calculation. These four are the Thornthwaite method for calculating unadjusted evapotranspiration (33,40), the crop consumptive use method of Blaney and Criddle (5), the model derived by Wiser from Thornthwaite's adjusted evapotranspiration model (49), and Penman's method for evapotranspiration calculation (29). Computer programs for each model were developed by the author or adapted for the IBM 360/65 configuration at the University of Tennessee Computer Center. Input requirements for each model are

²County yield estimates were provided by Mr. R. Hobson, Agricultural Statistician, Tennessee Crop Reporting Service, Nashville, Tennessee.

shown in Table II. A description of each model can be found in the review of literature. To standardize outputs for comparison purposes all water uses have been calculated in terms of mean inches per day except for the Wiser model which produces output in drought-days per month for each available soil moisture amount.

Calculation of drought-days by a soil moisture balance method requires a model of soil moisture status. The model used in these calculations was

$$SMS_i = SMS_{i-1} - ET + (P - RO)$$

where SMS_i is the soil moisture status, SMS_{i-1} is the soil moisture status of the previous day, ET is the amount of calculated evapotranspiration for that day, P is precipitation input, and RO is runoff loss from the system. Precipitation in excess of available soil storage is considered lost from the system. When available soil moisture is equal to or less than 0 inch a drought-day occurs. A negative available soil moisture level is not allowed in terms of model constraints where

$$0 \leq SMS_i \leq A.W.H.C.$$

Drought-days were calculated for each of seven available water-holding capacities: one, two, three, four, five, seven, and ten inches. Water use values from each model were used as input to the moisture balance equation producing drought-days which vary as the models themselves vary. Values from the Penman, Blaney-Criddle, and Thornthwaite 1948 models were used to calculate drought-days by climatic week and by

TABLE II
INPUT REQUIREMENTS FOR EACH WATER-USE MODEL

Requirements	Thornthwaite 1948	Blaney- Criddle	Thornthwaite- Wiser	Penman
Monthly Mean $^{\circ}\text{C}$	X			X
Monthly Mean $^{\circ}\text{F}$		X		
Monthly Mean Sun Percent		X		X
Monthly Mean Wind Run (miles/day)				X
Monthly Mean Relative Humidity				X
Monthly Mean Extra- terrestrial Radiation				X
Daily $^{\circ}\text{F}$			X	
Daily Precipitation			X	
Latitude			X	X
Reflection Coefficient				X
Crop Water-Use Coefficient		X		

calendar month. Due to the structure of the Wiser model program only drought-days per month were calculated for each available soil moisture level. Drought intensity was considered to be the number of drought-days occurring per week or per month.

IV. REGRESSIONS

To analyze the relative effectiveness of each water-use model in predicting yield responses, regressions were made. Crop yields derived from variety trials and from county yield estimates were standardized (as described above) to eliminate technological trend. These yield indices were regressed against weekly drought-days for those weeks comprising the growing season of each crop. Drought-days by weeks were used in evaluation of models for it was felt that these would provide better accuracy than monthly drought-day totals. They would also allow a look at the more critical periods during the growing season. The null hypothesis was that all other input factors being equal, the crop yield would vary inversely with number and occurrence of drought-day periods during the season. Selection of the best model to use for drought intensity probabilities was made on the basis of these regressions and evaluation of coefficients of determination. Total drought-days per month calculated by the selected model were also regressed against crop yields.

County yield averages for corn, cotton, and burley tobacco were evaluated using weekly drought-days for each moisture base.

Data analyses were performed on the IBM 360/65 at the University of Tennessee Computer Center. Data handling and analysis routines of the Statistical Analysis System (2) were employed. Stepwise multiple regression analysis and regression analysis of variance were calculated for each location. Significance was established at 10 percent.

CHAPTER III

RESULTS AND DISCUSSION

I. YIELD DATA

Data for yields of corn, cotton, and burley tobacco varieties were obtained from variety trial results. Corn data were evaluated from 1947 to 1970; cotton data were examined for the years 1949 to 1970; and tobacco yields for the years 1957 to 1970 were used. Appendix tables indicate availability of data for each crop for each location where it was tested. Of eight locations where corn was tested only six were considered to have sufficient and continuous data for testing. These are Greeneville, Knoxville, Crossville, Springfield, Spring Hill, and Jackson. Of the seven cotton testing locations only Fort Pillow, Ames Plantation, Jackson, and Knoxville had suitable lengths of record. All tobacco testing locations had sufficient data and were evaluated.

II. EVALUATION OF EVAPOTRANSPIRATION MODELS

Drought-days were calculated using evapotranspiration values derived from Penman's formula, from the Blaney-Criddle method, and from Thornthwaite's formula (see Materials and Methods, Chapter III). These drought-days were summed by climatic week and by calendar month for each station-year. Regressions of crop yields against drought-days for each available water holding capacity were used to evaluate the suitability

of each in describing the response of crop yield to drought intensities. For screening purposes drought-days within climatic weeks were used in the regressions to provide increased sensitivity of crop response over that of regressions against monthly totals where variation and timing of occurrence would be masked. Coefficients of determination from the regressions are in Tables III through V.

Crop yield-index variation proved to be insensitive to drought-days derived from the Penman method. The R^2 values of regressions of corn yields and yield indices against drought-days of the several water holding capacities did not vary significantly within locations (Table IV); however, among locations there were differences in R^2 . One would expect values of the coefficients of determination to decrease as the available water holding capacity of the soil increased. Penman-derived evapotranspiration values were larger than those calculated by the other methods, thereby producing drought-days at the higher moisture levels in excess of that number expected. Coefficients were the same or without a discernable pattern for each crop at each location.

The lack of response exhibited by Penman-derived drought-days is, perhaps, best explained by the fact that this method relies heaviest upon precise wind, sunshine, and humidity data. Values for these climatic data must be extrapolated from existing sites where these data are taken and the effectiveness of the method is lost. Of the locations evaluated only Knoxville was close to a station taking the required measurements. Lack of response at Knoxville can be attributed to location and variability of conditions from the Plant Science Farm to the airport.

TABLE III

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL CORN
YIELDS AGAINST WEEKLY^a DROUGHT-DAY TOTALS CALCULATED
BY THREE WATER-USE MODELS*

Method	Moisture Status inches	Y-R ^{2b}	YI-R ^{2c}	Y-R ²	YI-R ²	Y-R ²	YI-R ²
		<u>Greeneville</u>		<u>Knoxville</u>		<u>Crossville</u>	
Penman	1	.827	.826	.615	.560	.818	.730
	2	.828	.826	.614	.551	.796	.721
	3	.808	.826	.579	.518	.818	.687
	4	.828	.826	.608	.546	.818	.730
	5	.828	.826	.609	.550	.818	.730
	7	.828	.826	.600	.552	.749	.681
	10	.828	.826	.614	.559	.560	.487
Blaney- Criddle	1	.828	.826	.610	.547	.818	.729
	2	.736	.727	.602	.497	.816	.729
	3	.828	.735	.606	.561	.818	.710
	4	.828	.824	.588	.559	.767	.682
	5	.787	.787	.587	.532	.600	.526
	7	.756	.750	.429	.426	.408	.340
	10	.662	.679	.348	.250	.392	.370
Thorntwaite	1	.820	.824	.613	.560	.818	.701
	2	.778	.789	.600	.559	.659	.511
	3	.732	.756	.560	.528	.444	.417
	4	.669	.683	.467	.306	.396	.415
	5	.408	.411	.332	.262	.274	.258
	7	.286	.273	.101	.088	N.R.	N.R.
	10	N.R. ^d	N.R.	N.R.	N.R.	N.R.	N.R.
		<u>Springfield</u>		<u>Spring Hill</u>		<u>Jackson</u>	
Penman	1	.829	.802	.542	.544	.497	.489
	2	.831	.804	.536	.536	.518	.523
	3	.831	.803	.542	.543	.519	.521
	4	.831	.804	.538	.543	.479	.476
	5	.831	.804	.542	.543	.479	.474
	7	.831	.803	.541	.540	.423	.405
	10	.829	.804	.532	.534	.477	.482

TABLE III (continued)

Method	Moisture Status inches	Y-R ^{2b}	YI-R ^{2c}	Y-R ²	YI-R ²	Y-R ²	YI-R ²
Blaney- Criddle	1	.831	.803	.530	.532	.514	.516
	2	.831	.804	.540	.542	.511	.468
	3	.830	.803	.541	.538	.507	.508
	4	.831	.804	.537	.522	.483	.497
	5	.688	.638	.498	.498	.512	.485
	7	.636	.601	.221	.224	.453	.439
	10	.615	.655	.172	.174	.453	.445
Thorntwaite	1	.831	.804	.538	.540	.515	.516
	2	.831	.782	.526	.526	.475	.454
	3	.802	.793	.514	.515	.452	.459
	4	.720	.722	.414	.416	.485	.482
	5	.562	.571	.317	.322	.463	.466
	7	.491	.477	.145	.146	.423	.425
	10	.417	.384	.002	.002	.308	.301

* $P \geq .10$ for inclusion of specific weeks.

^aClimatic weeks included 9 through 27.

^bY-R² = Yield coefficients of determination.

^cYI-R² = Yield index coefficients of determination.

^dN.R. = No regression.

TABLE IV

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL
COTTON YIELDS AGAINST WEEKLY^a DROUGHT-DAY TOTALS CALCULATED
BY THREE WATER-USE MODELS*

Method	Moisture Status inches	Y-R ^{2b}	YI-R ^{2c}	Y-R ²	YI-R ²
		<u>Fort Pillow</u>		<u>Ames Plantation</u>	
Penman	1	.884	.859	.938	.936
	2	.885	.847	.938	.936
	3	.883	.864	.938	.936
	4	.885	.864	.938	.937
	5	.884	.863	.938	.937
	7	.885	.864	.938	.937
	10	.884	.863	.938	.936
Blaney- Criddle	1	.885	.863	.939	.937
	2	.884	.863	.938	.937
	3	.884	.864	.938	.936
	4	.884	.864	.939	.936
	5	.800	.818	.937	.937
	7	.528	.544	.810	.848
	10	.370	.298	.779	.800
Thorntwaite	1	.883	.864	.938	.936
	2	.884	.864	.938	.937
	3	.885	.863	.937	.936
	4	.793	.818	.938	.937
	5	.720	.749	.915	.926
	7	.238	.204	.808	.842
	10	.139	.189	.327	.360
		<u>Jackson</u>		<u>Knoxville</u>	
Penman	1	.611	.613	.622	.613
	2	.576	.578	.634	.624
	3	.481	.485	.639	.625
	4	.564	.609	.640	.614
	5	.575	.578	.638	.610
	7	.610	.613	.641	.628
	10	.370	.372	.639	.624

TABLE IV (continued)

Method	Moisture Status inches	Y-R ^{2b}	YI-R ^{2c}	Y-R ²	YI-R ²
Blaney- Criddle	1	.606	.609	.636	.622
	2	.598	.611	.632	.623
	3	.548	.551	.633	.627
	4	.333	.335	.608	.602
	5	.405	.405	.641	.316
	7	.299	.300	.396	.389
	10	.011	.011	.077	.076
Thorntwaite	1	.597	.600	.640	.623
	2	.580	.582	.640	.625
	3	.445	.446	.640	.628
	4	.216	.218	.334	.336
	5	.202	.203	.152	.176
	7	.116	.116	.038	.034
	10	.106	.107	N.R. ^d	N.R.

* $P \geq .10$ for inclusion of specific weeks.

^aClimatic weeks included 10 through 28.

^bY-R² = Yield coefficients of determination.

^cYI-R² = Yield index coefficients of determination.

^dN.R. = No regression.

TABLE V

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL
BURLEY TOBACCO YIELDS AGAINST WEEKLY^a DROUGHT-DAY TOTALS
CALCULATED BY THREE WATER-USE METHODS*

Method	Moisture Status inches	Y-R ^{2b}	YI-R ^{2c}	Y-R ²	YI-R ²
		<u>Greeneville</u>		<u>Rutledge</u>	
Penman	1	.795	.622	.653	.352
	2	.805	.606	.636	.370
	3	.805	.620	.652	.370
	4	.806	.621	.629	.370
	5	.806	.621	.641	.299
	7	.806	.621	.641	.299
	10	.806	.621	.641	.299
Blaney- Criddle	1	.804	.632	.653	.449
	2	.791	.634	.645	.369
	3	.805	.636	.644	.394
	4	.801	.624	.636	.449
	5	.806	.622	.635	.280
	7	.796	.599	.614	.306
	10	.657	.446	.321	.122
Thorntwaite	1	.800	.633	.633	.279
	2	.807	.623	.639	.395
	3	.793	.545	.643	.436
	4	.794	.096	.325	.422
	5	.510	.192	.415	.024
	7	.263	.060	.208	.024
	10	N.R. ^d	N.R.	.089	N.R.
		<u>Springfield</u>		<u>Spring Hill</u>	
Penman	1	.810	.653	.757	.769
	2	.775	.657	.756	.774
	3	.816	.637	.761	.772
	4	.818	.658	.764	.772
	5	.818	.658	.764	.767
	7	.818	.658	.756	.766
	10	.818	.659	.749	.774

TABLE V (continued)

Method	Moisture Status inches	Y-R ^{2b}	YI-R ^{2c}	Y-R ²	YI-R ²
Blaney- Criddle	1	.822	.620	.738	.771
	2	.822	.655	.764	.768
	3	.826	.603	.756	.770
	4	.825	.536	.760	.770
	5	.817	.643	.624	.772
	7	.785	.648	.717	.398
	10	.480	.236	.014	N.R.
Thornthwaite	1	.824	.655	.753	.773
	2	.823	.656	.763	.772
	3	.826	.650	.754	.770
	4	.823	.657	.743	.770
	5	.428	.453	.747	.494
	7	.523	.239	.406	.237
	10	.163	.062	N.R.	N.R.

* $P \geq .10$ for inclusion of specific weeks.

^aClimatic weeks included 14 through 30.

^bY-R² = Yield coefficients of determination.

^cYI-R² = Yield index coefficients of determination.

^dN.R. = No regression.

Values of R^2 for regressions in which drought-days derived from the Blaney-Criddle formula were the independent variables more closely approximate the expected reduction. The Blaney-Criddle formula used a crop water-use coefficient, temperature, and percent of yearly sunshine. Of these three factors the crop water-use value has the most latitude in that suitable ones for the climates and crops of Tennessee have not been fully evaluated. Using literature crop water-use values (5) the Blaney-Criddle-derived yield index values did exhibit a decreasing value at the higher A.W.H.C. levels.

The Thornthwaite method of calculating evapotranspiration also produced the expected decrease in numbers of drought-days at higher soil moisture capacities. However, in general, these R^2 values had a greater response across water holding capacities than did either of the other two methods discussed above. In terms of ease of use and response of yields to drought values this method has the advantage over the other two methods of calculating weekly drought. It is based on empirical relationships between temperature, daylength, and sunshine which exist in the humid eastern United States and requires as input mean monthly air temperature.

Evaluation of these three methods brought out some interesting relationships. At the one-inch A.W.H.C. level the corn variety trial data (Table III) R^2 values were approximately the same for each method. By ranking locations in order by increasing R^2 value one can see the relationship of stations in the amount of yield variation accounted for by drought conditions. Jackson appears as the station with the

least R^2 for corn and cotton (Tables III and IV); however, the coefficients of variation for these yield index values were consistently high (greater than 20 percent) which may or may not be a function of numbers of varieties tested, or the effects of climate, or some other more intangible production factor. Greeneville had highest R^2 values for corn, Ames Plantation had highest values for cotton regressions, and Spring Hill (the Middle Tennessee Experiment Station) had highest coefficients for burley tobacco (Table V). For each of these crops the data indicate moisture status to be more responsible for yield variation at these locations than at the others. An evaluation of those values will follow below.

A fourth method of calculating drought-days was employed which only calculated drought-days by calendar month. This procedure employs a modified Thornthwaite procedure in which values of ET are adjusted for daylength variation. This method was devised by E. H. Wiser and J. van Schlifgaarde (49). Tables VI through VIII contain coefficients of determination along with independent variables associated with each regression. Values for these coefficients are generally much less than corresponding coefficients for the weekly drought-day regressions. Independent variables entering into the regression equations reveal trends in significance. At low moisture levels variation in monthly totals for all growing season months tended to be significant while as the amount of soil water increased, the significant months tended to be those in the latter portion of the season. Total drought-days per year enters equations with corn and cotton much more than in the tobacco

TABLE VI

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL CORN YIELDS AGAINST MONTHLY DROUGHT-DAY TOTALS CALCULATED BY THE WISER METHOD FOR SIX LOCATIONS*

Moisture Status inches	Yield R^2_a	Independent Variables	Yield Index R^2_b	Independent Variables
<u>Crossville</u>				
1	.247	June, Aug., Sept.	.126	May, June, Aug., Sept., Total
2	.327	May, June, Aug., Sept., Total	.292	May, June, Aug., Sept., Total
3	.341	May, June, Aug., Sept.	.370	May, June, Aug., Sept., Total
4	.376	June, Aug.	.338	May, June, Aug., Total
5	.400	Aug., Sept., Total	.372	May, July, Aug., Total
7	.445	Aug., Sept., Total	.388	Aug., Sept.
10	.297	Aug., Sept., Total	.268	Aug., Sept., Total
<u>Greeneville</u>				
1	.511	May, June, July, Aug., Sept.	.487	May, June, July, Aug., Sept.
2	.537	May, June, July, Aug., Sept., Total	.519	May, June, July, Aug., Sept., Total
3	.558	May, June, July, Aug., Sept., Total	.531	May, July, Aug., Sept., Total
4	.651	May, June, July, Aug., Sept.	.629	May, June, July, Aug., Sept.
5	.651	May, June, July, Aug., Sept., Total	.680	May, June, July, Aug., Sept.
7	.703	June, July, Aug., Sept., Total	.511	June, July, Aug., Sept., Total
10	.419	July, Aug., Sept., Total	.415	July, Aug., Sept., Total
<u>Jackson</u>				
1	.251	June, July	.235	May, June, July, Aug., Sept., Total
2	.289	May, June, July, Aug., Sept., Total	.235	May, June, July
3	.340	May, June, July, Aug., Sept., Total	.306	May, June, July, Aug., Sept., Total
4	.380	May, June, July	.353	May, June, July

TABLE VI (continued)

Moisture Status	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
inches				
5	.372	May, June, July, Aug., Sept., Total	.324	May, June, July
7	.315	June, July, Aug., Sept., Total	.288	June, July, Aug., Sept., Total
10	.310	June, July, Aug., Sept., Total	.285	July, Aug., Sept., Total
		<u>Knoxville</u>		
1	.193	May, June, July, Sept., Total	.162	May, June, July, Aug.
2	.195	May, June, July, Aug., Sept.	.132	May, June, Aug., Total
3	.185	May, June, July, Aug., Sept., Total	.174	May, June, Aug., Total
4	.185	May, June, July, Aug., Sept.	.162	May, June, Aug., Total
5	.176	June, July, Aug., Sept.	.134	May, June, Aug., Sept., Total
7	.083	Aug., Sept.	.065	June, Aug., Sept.
10	.073	July, Aug., Sept.	.070	July, Aug., Sept.
		<u>Springfield</u>		
1	.155	May, June, Aug., Total	.152	May, June, Aug., Sept., Total
2	.260	May, June, July, Aug., Total	.222	June, July, Aug., Sept., Total
3	.269	May, June, July, Aug., Total	.183	May, June, July, Aug., Sept., Total
4	.302	May, July, Aug., Total	.201	May, July, Aug., Sept., Total
5	.236	June, July, Aug., Sept., Total	.184	June, July, Aug., Sept., Total
7	.225	Aug., Total	.161	Aug., Sept., Total
10	.356	Aug., Sept., Total	.329	Aug., Sept., Total
		<u>Spring Hill</u>		
1	.110	June, July, Aug., Sept., Total	.106	June, July, Aug., Sept., Total
2	.085	May, June, Aug., Sept., Total	.082	May, June, Aug., Sept., Total
3	.059	May, June, July, Aug.	.057	May, June, July, Aug.
4	.086	May, July, Sept.	.104	May, June, July, Sept.

TABLE VI (continued)

Moisture Status inches	Yield R^2 ^a	Independent Variables	Yield Index R^2 ^b	Independent Variables
5	.105	May, June, July, Sept.	.104	May, June, July, Sept.
7	.126	July, Aug., Sept.	.125	July, Aug., Sept.
10	.099	June, July, Aug., Sept.	.103	June, July, Aug., Sept., Total

* $P \geq .10$ for inclusion of specific months.

^aYield R^2 = Yield coefficient of determination.

^bYield Index R^2 = Yield index coefficient of determination.

TABLE VII

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL COTTON YIELDS AGAINST MONTHLY DROUGHT-DAY TOTALS CALCULATED BY THE WISER METHOD FOR FOUR LOCATIONS*

Moisture Status	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
inches				
		<u>Ames Plantation</u>		
1	.308	June, Sept., Total	.265	June, Sept., Total
2	.098	July, Total	.067	July, Total
3	.133	June, July, Sept., Total	.086	June, July, Sept.
4	.272	May, June, July, Aug., Sept.	.288	May, June, Aug., Sept., Total
5	.121	June, July, Sept., Total	.099	June, July, Sept., Total
7	.150	July, Aug., Sept., Total	.149	July, Aug., Sept., Total
10	.132	July, Aug., Sept., Total	.120	July, Aug., Sept., Total
		<u>Fort Pillow</u>		
1	.375	May, July	.523	May, June, July, Aug., Sept., Total
2	.464	May, July	.540	May, July, Aug., Sept., Total
3	.464	May, June, July, Aug., Sept., Total	.534	May, June, July, Aug., Total
4	.463	May, June, July, Aug., Total	.493	June, July, Aug., Sept.
5	.453	June, July, Aug., Sept.	.550	June, July, Sept., Total
7	.454	June, Aug., Sept., Total	.534	June, July, Aug., Sept., Total
10	.295	July, Aug., Sept.	.224	Aug., Sept.
		<u>Jackson</u>		
1	.047	May, July, Sept.	.047	May, July, Sept.
2	.173	May, June, Aug., Sept., Total	.173	May, June, Aug., Sept., Total
3	.243	May, July, Aug., Sept., Total	.243	May, July, Aug., Sept., Total
4	.244	May, June, July, Aug., Sept., Total	.245	May, June, July, Aug., Sept., Total

TABLE VII (continued)

Moisture Status inches	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
5	.099	June, July	.099	June, July
7	.115	June, July, Sept.	.115	June, July, Sept.
10	.109	July, Aug., Total	.109	July, Aug., Total
<u>Knoxville</u>				
1	.069	May, Aug., Total	.069	May, Aug., Total
2	.010	July	.010	July
3	.052	May, June, Sept.	.060	May, June, Sept.
4	.088	May, June, Sept.	.126	May, June, Aug., Sept., Total
5	.113	May, June, July, Aug., Sept.	.118	May, June, July, Aug., Sept.
7	.231	June, July, Sept., Total	.230	June, July, Sept., Total
10	.044	Sept.	.046	Sept.

*P ≥ .10 for inclusion of specific months.

^aYield R² = Yield coefficient of determination.

^bYield Index R² = Yield index coefficient of determination.

TABLE VIII

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL BURLEY TOBACCO YIELDS AGAINST MONTHLY DROUGHT-DAY TOTALS CALCULATED BY THE WISER METHOD FOR FOUR LOCATIONS*

Moisture Status inches	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
<u>Greeneville</u>				
1	.155	May, June, July	.383	May, June, Sept., Total
2	.457	May, July, Sept.	.402	May, June, July, Aug., Total
3	.497	May, July, Aug., Sept.	.398	May, June, July, Aug., Total
4	.373	May, June, July, Aug.	.372	May, July, Aug., Sept.
5	.362	May, June, July, Aug.	.329	May, June, July
7	.351	July, Aug., Sept., Total	.120	July, Aug.
10	.308	July, Sept., Total	.060	Aug.
<u>Rutledge</u>				
1	.072	June, Total	.181	May, July
2	.052	Total	.073	May, July
3	.050	Total	.056	May, July
4	.057	Total	.017	May
5	.192	June, Sept.	.025	May
7	.207	June, July, Aug.	N.R.	
10	.203	July, Aug.	.009	Aug.
<u>Springfield</u>				
1	.720	May, June, July, Aug., Sept., Total	.441	May, June, July, Aug., Total
2	.269	July, Aug., Sept., Total	.345	May, July
3	.136	June, Aug.	.378	May, June, July
4	.216	June, July, Aug.	.184	July

TABLE VIII (continued)

Moisture Status inches	Yield R^2 ^a	Independent Variables	Yield Index R^2 ^b	Independent Variables
5	.376	June, July, Aug., Sept., Total	.169	July
7	.243	June, Sept., Total	.133	July
10	.406	July, Aug., Sept.	.097	July
<u>Spring Hill</u>				
1	.417	May, Aug., Sept.	.315	July, Sept., Total
2	.473	May, July, Sept.	.162	June, July
3	.564	May, June, July, Aug., Sept., Total	.151	June, July
4	.411	May, June, Sept.	.203	May, June, July
5	.557	May, June, July, Aug., Sept.	.287	May, June, July
7	.286	June, Sept.	.181	June, July
10	.072	Aug., Sept.	.061	Aug.

* $p \geq .10$ for inclusion of specific months.

^aYield R^2 = Yield coefficient of determination.

^bYield Index R^2 = Yield index coefficient of determination.

regressions. In general, the R^2 values would be expected to be lower for monthly periods than for weekly periods. This reduction is due to the way monthly totals mask the variation of moisture status which occur within months and to the decrease in number of independent variables able to be entered into the regression equation. The former factor is a function of the variability of moisture status; the latter is a function of the way a stepwise multiple regression procedure considers variables for entry into the equation. The R^2 values did not decrease as the available water holding capacity increased exhibiting no discernable pattern.

III. VARIETY TRIAL DATA EVALUATION

Planting and harvesting dates vary from year to year as a function of temperature and precipitation. Recommended planting dates were considered in selecting independent variables for the regressions; however, to encompass the variation in weather which would lead to planting and harvesting schedule adjustments, the growing season considered was lengthened for each period by two to three weeks. Therefore, the time period considered for corn was from April 26 through September 5. For cotton, a growing season from May 3 through September 15 was used. Burley tobacco was given a season beginning June 1 and ending September 26. A table in the Appendix explains the coding for climatic weeks as they appear in the regression analyses.

Yield data were analyzed for elimination of effects of technological advance by fitting the data to a first-order time series (least squares

method). The equation was of the general form

$$\hat{y} = \mu \pm \beta X$$

where $\hat{y}$ was the yield estimate and X was the coded time variable in years. Low coefficients of determination from these regressions indicate a general lack of linearity in the data and a variation dependent upon factors other than increased application of improved agricultural methodology. Tobacco values were slightly higher than those from corn or cotton (Table IX).

Corn Variety Trial Analyses

Monthly moisture deficit at Crossville accounted for 41.6 and 42.5 percent of the variation in yield index at the three- and four-inch bases (Table X). Values of R^2 varied from .213 at one-inch to .289 at the two-inch base. Monthly deficits were of minor significance on soils with ten inches of available water.

At one-inch soil moisture base all months contributed significantly to yield variation at Greeneville (Table X). This was somewhat borne out in the significant weeks above, but the R^2 value for months was .739 or 8.5 points less than that for the weekly regression for the same soil moisture. Coefficients of determination decreased except at the three-inch base (with a minor peak of .607) to a value of .147 for the ten-inch base in September. This last value was of little importance due to time of occurrence and the soil base itself.

TABLE IX

COEFFICIENTS OF DETERMINATION FROM FIRST-ORDER LEAST SQUARES
 CURVE FITTING OF VARIETY TRIAL DATA TRENDS AT
 SEVERAL LOCATIONS FOR THREE CROPS

Location	Coefficient of Determination
<u>Corn</u>	
Crossville	.314
Greeneville	.009
Jackson	.015
Knoxville	.238
Springfield	.126
Spring Hill	.000
<u>Cotton</u>	
Ames Plantation	.035
Fort Pillow	.127
Jackson	.000
Knoxville	.002
<u>Tobacco</u>	
Greeneville	.422
Rutledge	.330
Springfield	.544
Spring Hill	.013

TABLE X

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL CORN YIELDS AGAINST MONTHLY DROUGHT-DAY TOTALS CALCULATED BY THE THORNTWAITE METHOD FOR SIX LOCATIONS*

Moisture Status inches	Yield R ² a	Independent Variables	Yield Index R ² b	Independent Variables
<u>Crossville</u>				
1	.269	April, May, June, July, Aug., Sept.	.213	April, May, June, July, Aug., Sept.
2	.284	June, July, Aug.	.289	May, June, July, Aug., Sept.
3	.324	Aug., Sept.	.416	May, July, Aug., Sept.
4	.385	May, July, Aug.	.425	May, Aug., Sept.
5	.266	Aug., Sept.	.271	Aug., Sept.
7	.018	Sept.	.002	Sept.
10	N.R.		N.R.	
<u>Greeneville</u>				
1	.745	April, May, June, July, Aug., Sept.	.739	April, May, June, July, Aug., Sept.
2	.562	May, July, Aug., Sept.	.537	May, June, July, Aug., Sept.
3	.607	May, June, July, Aug., Sept.	.607	May, June, July, Aug., Sept.
4	.544	May, June, July, Aug., Sept.	.536	May, June, July, Aug., Sept.
5	.402	June, July, Aug., Sept.	.399	July, Aug., Sept.
7	.434	July, Aug., Sept.	.423	July, Aug., Sept.
10	.155	Sept.	.147	Sept.
<u>Jackson</u>				
1	.292	April, June, July, Aug., Sept.	.263	April, June, July, Aug., Sept.
2	.307	May, June, July	.274	May, June, July
3	.331	May, June, July, Aug., Sept.	.307	May, June, July, Aug.
4	.329	May, June, July, Aug., Sept.	.308	May, June, July, Aug., Sept.

TABLE X (continued)

Moisture Status	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
inches				
5	.307	June, July, Aug., Sept.	.286	June, July, Aug., Sept.
7	.251	July, Aug., Sept.	.242	July, Aug., Sept.
10	.180	July, Aug., Sept.	.175	July, Aug., Sept.
		<u>Knoxville</u>		
1	.303	April, May, June, Aug., Sept.	.227	April, May, June, Aug.
2	.198	May, June, July, Aug.	.204	May, July, Aug., Sept.
3	.124	May, June, July, Aug., Sept.	.096	May, June, July, Aug., Sept.
4	.065	Aug., Sept.	.030	Aug.
5	.080	Aug., Sept.	.053	July, Aug., Sept.
7	.031	Aug., Sept.	.013	Aug.
10	N.R.		N.R.	
		<u>Springfield</u>		
1	.357	April, May, June, July, Aug., Sept.	.366	April, May, June, July, Aug., Sept.
2	.443	May, June, July, Aug., Sept.	.369	May, June, July, Aug., Sept.
3	.310	May, June, July, Aug., Sept.	.252	June, July, Aug., Sept.
4	.292	June, July, Aug., Sept.	.275	June, July, Aug.
5	.345	June, July, Aug., Sept.	.339	June, July, Aug., Sept.
7	.401	Aug.	.360	Aug., Sept.
10	.420	Aug., Sept.	.364	Aug., Sept.
		<u>Spring Hill</u>		
1	.145	April, May, June, July, Aug., Sept.	.142	April, May, June, July Aug., Sept.
2	.049	April, May, July, Aug., Sept.	.048	April, May, July, Aug., Sept.
3	.083	May, June, July, Sept.	.082	May, June, July, Sept.
4	.112	June, July, Aug., Sept.	.111	June, July, Aug., Sept.

TABLE X (continued)

Moisture Status inches	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
5	.066	June, July, Sept.	.066	June, July, Sept.
7	.103	July, Sept.	.106	July, Sept.
10	.002	Sept.	.002	Sept.

* $P \geq .10$ for inclusion of specific months.

^aYield R^2 = Yield coefficient of determination.

^bYield Index R^2 = Yield index coefficient of determination.

Effects of monthly drought totals at Jackson indicated a different trend (Table X). Values of R^2 increased from .263 at the one-inch base to a maximum of .308 for a four-inch base and decreased to a minimum of .175 at the ten-inch base. Monthly drought from May through September was significant at the four-inch moisture base in these regressions.

Significant monthly drought-day totals on corn yields at Knoxville can be seen in Table X. For index values at the one-inch base the significant months were April, May, June, and August with a coefficient of .227. These decreased to the seven-inch status in which August drought-days explained only 1.3 percent of the yields. No drought variables were significant at the ten-inch base. Coefficients of determination were less for these regressions than for those using weekly drought totals. This was due to the masking of weekly variation in monthly totals.

Effects of variation in monthly drought-days on yield, index at Springfield differed from results obtained at other locations (Table X). Coefficients of determination for both yield and yield index indicated a minimum at the three- and four-inch moisture bases. The R^2 values for the one- and ten-inch bases were approximately equal although the significant months were quite different. Deficits occurring in June, July, and August were significant at the lower moisture levels. August and September drought accounted for one-third of the yield index variation. These significant months were to be expected; although the corn crop is harvested prior to the end of September, these results indicated

the lengthening of growing season is possible on soils with greater water holding capacities.

Monthly deficit conditions generally accounted for less than 15 percent of yield index variation at Spring Hill (Table X). Significant months of May, June, July, and August include most of the soil moisture variation. Low R^2 values here were a function of masking of deficit variation within months.

Of the three crops evaluated in this study only corn varieties were tested at Crossville in variety trials. Weekly drought variation accounted for 70.1 percent of yield index variation at the one-inch base (Table XI). Values of R^2 decrease 19 points to the two-inch base with a 9.3 point reduction to the three-inch level. Moisture deficits accounted for little over one-half of yield variation on a two-inch base. Only slightly more than 25 percent of variation was explained on the five-inch base. The significant week at this level was August 23-29. No variables were significant at either the seven-inch or at the ten-inch base.

Drought-days at Greeneville on a one-inch moisture base accounted for 82 percent of corn yield index variation with significant weeks occurring around the first of May (X9-X10), the month of June (X13-X20), and the weeks from July 26 through August 29 (X22-X26) (Table XII). Coefficients decreased as reported earlier; however, the weeks of the season beginning July 12 appeared as significant in all regressions. No variables were significant at a ten-inch base. In general R^2 values for yield index were from .2 to 2.4 percentage points greater than those

TABLE XI

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL CORN YIELDS AGAINST WEEKLY DROUGHT-DAY TOTALS CALCULATED BY THE THORNTWHAITE METHOD FOR SIX LOCATIONS*

Moisture Status	Yield R ² _a	Independent Variables	Yield Index R ² _b	Independent Variables
inches				
		<u>Crossville</u>		
1	.818	X9-X15, X17-X27	.701	X9, X10, X13-X15, X17-X26
2	.659	X11, X14, X15, X17-X22, X25-X27	.511	X12, X14-X16, X18-X20, X22, X23, X25, X27
3	.444	X22-X27	.417	X13, X22-X24, X26
4	.396	X13, X19, X25, X27	.415	X13, X19, X25, X26
5	.274	X26, X27	.258	X26
7	N.R.		N.R.	
10	N.R.		N.R.	
		<u>Greeneville</u>		
1	.820	X9-X11, X14-X20, X22-X26	.824	X9-X10, X13-X20, X22-X26
2	.778	X11-X25	.789	X11-X27
3	.732	X14-X21, X23-X27	.756	X14-X20, X22-X27
4	.669	X13, X18, X20-X27	.683	X14, X17, X20-X27
5	.409	X23, X25, X27	.411	X21, X24, X25, X27
7	.286	X22, X24, X27	.273	X23, X24, X27
10	N.R.		N.R.	
		<u>Jackson</u>		
1	.515	X9, X11, X14, X16-X18, X22, X23, X25, X27	.516	X9, X11, X14, X16-X18, X21-X25, X27
2	.475	X11, X12, X14-X18, X21, X22, X24, X27	.454	X13-X18, X22, X27
3	.452	X15, X17-X20, X22-X25	.459	X12, X14, X15, X19-X24, X27
4	.485	X15, X17, X19, X20, X22, X23, X25, X27	.482	X15, X17, X19, X20, X22-X24, X27

TABLE XI (continued)

Moisture Status inches	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
5	.463	X19, X21, X22, X25-X27	.466	X16, X19, X21, X22, X25-X27
7	.424	X19, X24-X27	.425	X19, X24-X27
10	.308	X21, X24-X27	.301	X21, X24-X27
<u>Knoxville</u>				
1	.613	X10-X18, X20-X26	.560	X9, X10, X12, X15-X27
2	.600	X13, X14, X16-X27	.559	X10-X16, X18, X20, X22-X27
3	.560	X13-X16, X18-X22, X24-X27	.528	X12, X14-X16, X18, X20-X22, X24-X27
4	.467	X17-X26	.306	X18-X26
5	.332	X21, X25, X26, X27	.262	X19-X21, X25-X27
7	.101	X25-X27	.088	X25-X27
10	N.R.		N.R.	
<u>Springfield</u>				
1	.831	X9-X13, X16, X18-X27	.804	X9, X10, X12, X13, X18-X24, X26, X27
2	.831	X11-X20, X22-X27	.782	X13, X14, X16-X18, X20-X27
3	.802	X13-X20, X23-X27	.793	X13-X21, X23-X27
4	.720	X16-X27	.722	X16-X27
5	.562	X19, X20, X23-X27	.571	X16, X19, X21, X23-X27
7	.491	X21, X23, X25-X27	.477	X21, X23, X25-X27
10	.417	X23, X26-X27	.384	X23, X25, X26
<u>Spring Hill</u>				
1	.538	X12-X18, X20, X23-X27	.540	X9, X11, X12-X17, X19, X22-X24, X26, X27
2	.526	X11-X17, X20, X22-X24, X26, X27	.526	X11-X17, X20, X22-X24, X26, X27
3	.514	X12, X16-X18, X21-X24, X26, X27	.515	X12, X16-X18, X21-X24, X26, X27
4	.414	X15, X16, X19-X27	.416	X15, X16, X19-X27

TABLE XI (continued)

Moisture Status	Yield R^2_a	Independent Variables	Yield Index R^2_b	Independent Variables
inches				
5	.317	X17, X19-X22, X24-X27	.322	X17, X20-X27
7	.145	X18, X23, X27	.146	X18, X23, X27
10	.002	X25	.002	X25

* $p \geq .10$ for inclusion of specific weeks.

^aYield R^2 = Yield coefficient of determination.

^bYield Index R^2 = Yield index coefficient of determination.

TABLE XII

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL COTTON YIELDS AGAINST MONTHLY DROUGHT-DAY TOTALS CALCULATED BY THE THORNTWHAITE METHOD FOR FOUR LOCATIONS*

Moisture Status inches	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
<u>Ames Plantation</u>				
1	.673	May, June, July, Aug., Sept.	.634	May, June, July, Aug., Sept.
2	.579	July, Sept.	.542	July, Sept.
3	.620	July, Aug., Sept.	.564	July, Aug., Sept.
4	.412	June, July, Aug., Sept.	.391	June, July, Aug., Sept.
5	.370	June, July, Sept.	.427	June, July, Sept.
7	.378	July, Aug., Sept.	.403	July, Aug., Sept.
10	.583	July, Aug., Sept.	.641	July, Aug., Sept.
<u>Fort Pillow</u>				
1	.710	April, May, June, July, Aug., Sept.	.670	April, May, July, Aug., Sept.
2	.380	June, July, Aug., Sept.	.417	June, July, Aug., Sept.
3	.413	June, July, Aug., Sept.	.460	June, July, Aug., Sept.
4	.383	June, July, Aug., Sept.	.421	May, June, July, Aug., Sept.
5	.326	Aug.	.266	July, Aug.
7	.208	Aug., Sept.	.135	Aug., Sept.
10	.134	Aug., Sept.	.118	Aug.
<u>Jackson</u>				
1	.011	May	.011	May
2	.040	June	.039	June
3	.118	June, July, Aug.	.118	June, July, Aug.
4	.139	May, June, July, Aug., Sept.	.140	May, June, July, Aug., Sept.

TABLE XII (continued)

Moisture Status	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
inches				
5	.013	July	.013	July
7	.025	Aug.	.025	Aug.
10	.088	Aug., Sept.	.088	Aug., Sept.
<u>Knoxville</u>				
1	.039	April, May, Aug.	.015	April
2	.088	May, June, July, Sept.	.094	May, June, July, Sept.
3	.066	May, Sept.	.071	May, Sept.
4	.195	June, July, Aug., Sept.	.202	June, July, Aug., Sept.
5	.028	Sept.	.030	Sept.
7	.023	Aug.	.020	Aug.
10	N.R.		N.R.	

*P ≥ .10 for inclusion of specific months.

^aYield R² = Yield coefficient of determination.

^bYield Index R² = Yield index coefficient of determination.

for yield indicating that trend might have been less here than elsewhere.

Evaluation of corn response to weekly soil moisture deficits at Jackson were approximately the same for both yield and yield index (Table XI). Moisture deficit accounted for 51.6 percent of yield index variation at the one-inch base. For moisture bases from two to seven inches coefficients were approximately equal varying from 42.5 percent at the seven-inch base to a maximum of 48.2 percent at the four-inch base. Drought at the ten-inch availability accounted for 30.1 percent of variation.

Drought effects on corn yields at Knoxville follow as the trend established earlier in this chapter. Table XI presents the coefficients of determination and significant independent variables contributing to yield variation. At the one-inch moisture base more weeks were significant for the unadjusted yield variation than there are for the yield index values. Critical periods appearing in the index evaluation occurred at the last of April--first of May (X9-X10) and the months of June through August (X15-X27). These variables accounted for 56 percent of the variation in yield as evaluated by the index. At intermediate moisture bases (two to five inches) the significant weeks occurred later in the season but the variation explained decreased to 26 percent. At seven inches of water the last two weeks in August were significant but only accounted for approximately 9 percent in yield variation. Index R^2 values were less than those for the yield values.

indicating that the yield values contained some variation due to technological trend.

Weekly drought occurrence at the one-inch base accounted for 80.4 percent of corn yield index variation at Springfield. Values of R^2 remained approximately constant through the three-inch level (Table XI) but decreased 7 points to the four-inch base and 15 points, to 57.1 percent, at the five-inch base. Moisture deficits at the higher water availability levels accounted for less than 50 percent of yield index variation. At the three lowest moisture bases significant weeks coincided with periods at planting and germination. At the higher levels weeks coincided with dry weeks in July and August when tasseling occurs and the kernels are filling.

Moisture deficit variation within the one-, two-, and three-inch bases accounted for 54.0, 52.6, and 51.5 percent of corn yield index variation at Spring Hill, respectively (Table XI). These R^2 values were not very different from those of the yield regressions; this indicated little effect at this location due to technological trend. At moisture bases greater than or equal to four inches, 40 percent or less of the yield variation was accounted for by moisture deficit.

Cotton Variety Trial Analyses

Cotton was the only crop of the three considered in this work which was grown at Ames Plantation. Monthly drought totals showed some differences between yield and yield index regressions (Table XII). In general differences ranged between two and six percentage points. The

R^2 trend showed a minimum of .391 at the four-inch base with a second peak at the ten-inch base. Behavior of the regression at this point cannot be explained.

Monthly drought totals at Fort Pillow accounted for 67 percent of yield index variation at a one-inch moisture base with a subsequent decrease in R^2 values of a minimum of .118 at the ten-inch base. Differences between yield and index regressions were more pronounced in the monthly regressions (Table XII, page 50). Up to 7.3 points difference at the seven-inch base indicates a trend in monthly evaluation which is not evidenced in a weekly analysis.

Regressions of monthly drought-day totals at Jackson against cotton yields were low (Table XII) and the trend of R^2 values exhibited no obvious reflection of reality.

Just as at Jackson, effects of monthly drought-day totals were slight at Knoxville (Table XII). Drought on a four-inch base accounted for 20.2 percent of yield variations; monthly totals lacked variation due to periodic drought occurrence within the month.

Regressions of weekly drought-day totals against cotton yields at Ames Plantation revealed an interesting trend. Coefficients of determination at moisture availabilities from one to four inches varied little among themselves or between yield and yield index regressions. Moisture deficits on these soils accounted for approximately 94 percent of yield variation with 84.2 percent of the yield variation explained by deficits on soils with seven inches of available water (Table XIII).

TABLE XIII

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL COTTON YIELDS AGAINST WEEKLY DROUGHT-DAY TOTALS CALCULATED BY THE THORNTWHAITE METHOD FOR FOUR LOCATIONS*

Moisture Status	Yield R ² _a	Independent Variables	Yield Index R ² _b	Independent Variables
inches				
		<u>Ames Plantation</u>		
1	.938	X12, X15, X17, X18, X20, X23-X25, X27	.936	X10, X12, X14, X17, X18, X20, X21, X24-X27
2	.938	X11, X13, X15, X18-X20, X23, X24, X26, X27	.937	X11, X12, X17, X18, X21-X24, X26, X27
3	.937	X15-X21, X25-X27	.936	X15, X16, X19-X26
4	.938	X15, X16, X18-X23, X26, X27	.937	X15, X22, X24-X27
5	.915	X17-X23, X25, X26	.926	X17-X23, X25-X27
7	.808	X18, X21, X22, X24-X27	.842	X20-X22, X24-X27
10	.327	X22, X26	.360	X23, X27
		<u>Fort Pillow</u>		
1	.833	X10, X12, X13, X17, X20-X25	.864	X12-X14, X17, X18, X20, X21, X23-X27
2	.884	X11, X12, X14, X15, X17, X18, X20-X23	.864	X12-X16, X20-X23, X25-X27
3	.885	X13-X15, X17-X24, X26, X27	.863	X12-X20, X23, X24, X26
4	.793	X13, X16-X18, X20-X23, X26-X27	.818	X13, X15-X18, X21, X23-X27
5	.720	X16, X17, X22-X27	.749	X16-X19, X23, X24, X26, X27
7	.238	X21-X24, X27	.204	X24
10	.139	X24, X25	.189	X24-X26
		<u>Jackson</u>		
1	.597	X11, X13, X15-X26	.600	X11, X13, X15-X26
2	.580	X12-X14, X17-X21, X23, X24, X26, X27	.582	X12-X14, X17-X21, X23, X24, X26, X27
3	.445	X12, X14, X15, X17, X19-X21, X23-X25, X27	.446	X12, X14, X15, X17, X19-X21, X23-X25, X27
4	.216	X17, X18, X20, X25	.218	X17, X18, X20, X25

TABLE XIII (continued)

Moisture Status	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
inches				
5	.202	X18, X20-X23, X25, X27	.203	X18, X20-X23, X25, X27
7	.116	X19, X25-X27	.116	X19, X25-X27
10	.106	X24-X26	.107	X24-X26
		<u>Knoxville</u>		
1	.640	X11, X14, X15, X17, X19, X21, X24, X25, X27	.623	X10, X11, X14, X15, X17, X24, X27
2	.640	X10, X17-X24, X27	.625	X10, X17, X18, X20-X25
3	.640	X14, X15, X17-X19, X21-X26	.628	X14-X16, X18, X19, X22-X26
4	.334	X17, X20, X22-X24, X27	.336	X17, X20, X22-X24, X27
5	.152	X19, X21, X27	.176	X19, X21, X23, X26, X27
7	.038	X27	.034	X27
10	N.R.		N.R.	

* $p \geq .10$ for inclusion of specific weeks.

^aYield R² = Yield coefficient of determination.

^bYield Index R² = Yield index coefficient of determination.

of R^2 remained fairly constant for the one-, two-, and three-inch base amounts with drought on four-inch soils accounting for only 33.6 percent of yield variation. Hardly any difference between cotton yield regression R^2 and cotton yield index R^2 were evidenced at Knoxville. This indicates that effects of trend on yields at Knoxville were minimal whereas other factors not examined in this study were more important to explain yield values.

Burley Tobacco Variety Trial Analyses

Significant monthly variation in drought-day totals on a one-inch moisture capacity in relation to tobacco yield response occurred in May, June, and July at Greeneville (Table XIV). These months collectively accounted for 24.2 percent of yield index variation. Values of R^2 were greatest at the two- and three-inch bases. May, June, and July moisture stresses were common to these two levels. At the four-inch base the R^2 decreased to .302; values of R^2 for soils with greater available water exhibited even greater reduction.

Monthly drought variation at Rutledge accounted for 14.5 percent of the yield index variation at the one-inch moisture base (Table XIV). Values of R^2 decreased to .014 at the seven-inch base. No month was significant at the ten-inch level. Values were, again, lower for yield index than for the unadjusted yield.

Months during which soil moisture status became critical for tobacco at Springfield can be seen in Table XIV. Deficits on soils with a one-inch base accounted for 51.8 percent of yield index variation.

TABLE XIV

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL BURLEY TOBACCO YIELDS AGAINST MONTHLY DROUGHT-DAY TOTALS CALCULATED BY THE THORNTHWAITE METHOD FOR FOUR LOCATIONS*

Moisture Status inches	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
<u>Greeneville</u>				
1	.201	April, July	.242	May, June, July
2	.427	May, July, Sept.	.345	May, June, July
3	.298	May, July, Sept.	.338	May, June, July, Sept.
4	.244	May, July, Sept.	.302	May, July, Aug.
5	.183	July, Aug., Sept.	.060	July
7	.117	Aug., Sept.	.060	Aug.
10	N.R.		N.R.	
<u>Rutledge</u>				
1	.291	June, Sept.	.145	May, July, Sept.
2	.218	June, Sept.	.014	July
3	.184	June, Sept.	.045	May
4	.194	June, July, Aug.	.010	Aug.
5	.176	July, Aug.	.012	Aug.
7	.217	Aug., Sept.	.014	Sept.
10	.089	Aug.	N.R.	
<u>Springfield</u>				
1	.521	April, May, July, Sept.	.518	Apr., May, June, Aug., Sept.
2	.132	June	.474	May, July, Sept.
3	.299	May, June, July, Sept.	.362	May, July, Aug.
4	.334	June, Aug., Sept.	.176	July

TABLE XIV (continued)

Moisture Status inches	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
5	.376	July, Aug., Sept.	.210	June, July
7	.413	July, Aug.	.174	July, Aug.
10	.163	Aug.	.062	Sept.
<u>Spring Hill</u>				
1	.428	May, Sept.	.146	April, June, July
2	.457	May, June, Sept.	.113	June, July
3	.548	May, June, Sept.	.260	May, June, July
4	.358	June, Sept.	.168	June, July
5	.329	June, Sept.	.164	July, Aug.
7	.208	July	.228	July, Sept.
10	N.R.		N.R.	

*P ≥ .10 for inclusion of specific months.

^aYield R² = Yield coefficient of determination.

^bYield Index R² = Yield index coefficient of determination.

Critical months roughly coincided with planting, the first month after planting, and the period prior to harvest. Values of R^2 decreased from .474 at a two-inch base to .062 at the ten-inch moisture base.

Monthly drought-day regressions for tobacco at Spring Hill exhibited no obvious pattern (Table XIV). These results indicate that soil moisture status was more critical at Spring Hill than at any other tested location and the unirrigated tobacco grown here would do best on soils with greater than five inches of available water.

Table XV shows tobacco yield regressions against weekly drought-day totals at Greeneville. At the one- and two-inch moisture bases weekly drought-day totals accounted for 63.3 and 62.3 percent of variation in variety yield indices, respectively. The R^2 values decreased to .545 at the three-inch level then decreased greatly for the four-inch and greater soil moisture storage levels. No significant regression could be performed at the ten-inch level. The nature of these values indicated that tobacco grown at Greeneville encountered significant sources of yield variation due to moisture stress on soils with three inches or less of available water. Tobacco is a shallow rooted crop and probably lacks root development to utilize moisture in excess of a three-inch base.

Burley tobacco was the only crop evaluated at Rutledge for the variety trials. Table XV shows the statistics for this location. Weekly variation in moisture deficit on a one-inch base accounted for 27.9 percent of the variation in yield index with the weeks beginning June 21, July 5, and July 19 being the only significant variables. The highest R^2 value was at the three-inch base with significant periods occurring

TABLE XV

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF VARIETY TRIAL BURLEY TOBACCO YIELDS AGAINST WEEKLY DROUGHT-DAY TOTALS CALCULATED BY THE THORNTHWAITE METHOD FOR FOUR LOCATIONS*

Moisture Status inches	Yield R ^{2a}	Independent Variables	Yield Index R ^{2b}	Independent Variables
<u>Greeneville</u>				
1	.800	X17, X19, X20, X23, X26, X27, X29	.633	X17-X21, X23, X24, X28, X29
2	.807	X17, X20-X22, X25, X28, X30	.623	X18, X20-X26, X28, X30
3	.793	X18, X20, X21, X26, X27, X29	.545	X18, X22, X24-X27
4	.794	X21-X23, X25-X30	.096	X21, X29
5	.510	X19, X26, X27, X30	.192	X19, X27, X28
7	.263	X24, X30	.060	X24
10	N.R.		N.R.	
<u>Rutledge</u>				
1	.633	X17-X19, X23, X25, X27, X28, X30	.279	X17, X19, X21
2	.639	X18, X25, X27, X28, X30	.395	X17, X18, X20, X21, X25
3	.643	X17-X19, X26, X27	.436	X17, X18, X20, X25, X28, X29
4	.325	X30	.422	X17, X19, X21, X22, X28, X30
5	.415	X23, X28	.024	X25
7	.208	X30	.024	X30
10	.089	X27	N.R.	
<u>Springfield</u>				
1	.824	X17, X19, X22, X23, X25, X26, X29	.655	X19, X20, X23-X26, X29
2	.823	X18, X19, X21, X24, X25, X27, X29, X30	.656	X18, X19, X21, X22, X27, X29
3	.826	X17, X21-X24, X27	.650	X19-X21, X24, X25, X27, X29
4	.824	X18, X19, X21-X25, X28-X30	.657	X17-X21, X24, X25, X27

TABLE XV (continued)

Moisture Status inches	Yield R^2 ^a	Independent Variables	Yield Index R^2 ^b	Independent Variables
5	.428	X21, X22, X24, X27, X28	.453	X20, X22-X24, X30
7	.523	X21, X22, X27, X28, X30	.239	X22, X28, X30
10	.163	X28	.062	X24
<u>Spring Hill</u>				
1	.753	X17, X19, X20, X22, X28, X29	.773	X17, X21, X22, X24, X26-X28, X30
2	.763	X17, X18, X20-X23, X26	.772	X18-X20, X24, X26, X27, X29, X30
3	.754	X17, X24, X26-X30	.770	X17, X20, X21, X25-X27, X30
4	.743	X18, X23, X24, X26, X28, X29	.771	X17, X21, X24, X26-X30
5	.747	X18, X25	.494	X17, X22, X26-X29
7	.406	X18, X29	.237	X18, X27, X29
10	N.R.		N.R.	

* $P \geq .10$ for inclusion of specific weeks.

^aYield R^2 = Yield coefficient of determination.

^bYield Index R^2 = Yield coefficient of determination.

in the middle of June, the second week in July, the third week in August, and the first two weeks in September. Moisture deficit accounted for only 2.4 percent of yield variation at the five- and seven-inch bases with there being no significant regression at the ten-inch base. The R^2 values for yield index were generally less than those for regressions with the unadjusted yield value. This difference can be attributed to the trend effect which was deleted from the actual yield values.

Burley tobacco variety yield index regression statistics are shown in Table XV for Springfield. At moisture bases from one to four inches the drought-days accounted for approximately 65 percent of the yield index variation. The R^2 values at bases of five inches and more decreased to a minimum of 6.2 percent at the ten-inch moisture base. Tobacco grown at Springfield on soils with greater than four inches of available water had significant sources of yield variation other than soil moisture availability to the tobacco root system.

Coefficients of determination associated with the yield index by weekly drought-day regressions for Spring Hill were larger than for any other station at which tobacco was tested (Table XV). Values of approximately .771 were produced for the one-, two-, three-, and four-inch moisture bases. Values of R^2 decreased greatly for the remaining moisture levels. There was no significant regression possible for the ten-inch status.

IV. CROP REPORTING SERVICE DATA EVALUATION

County yield estimates for corn, cotton, and burley tobacco for all years available between 1947 and 1970 were analyzed for technological trend by fitting a first-order time series to the data. The equation had the general form

$$\hat{y} = \mu \pm \beta X$$

where $\hat{y}$ was the yield estimate and X was the coded time variable in years. Coefficients of determination from these regressions indicated a high degree of linearity of county data for corn and tobacco (Table XVI). In most cases county yield estimates exhibited greater than 50 percent fit with the trend line as compared with a generally low degree of fit of variety trial data when analyzed in the same fashion (Table IX, page 41). Differences between the two types of data which can account for these results are: (1) county yield estimates are just that, estimates, and not actual data results; (2) estimates reflect effects of technology more than do variety trial results in that advances in agricultural practice are incorporated into variety trials from the outset while such technological advance has a time lag before general adoption by the producer; and (3) because county estimates are a single figure per year much of the internal variation is hidden such that the estimate reflects subjectivity more than reality.

In the preceding section the interpretation of variety trial yield index regressions could be more closely compared to that of the yield

TABLE XVI

COEFFICIENTS OF DETERMINATION FROM FIRST-ORDER LEAST
SQUARES CURVE FITTING OF COUNTY YIELD ESTIMATES
FOR THREE CROPS AT SEVERAL LOCATIONS

County	Coefficient of Determination
<u>Corn</u>	
Benton	.683
Bledsoe	.612
Carroll	.621
Coffee	.408
Cumberland	.658
Fayette	.591
Franklin	.334
Gibson	.634
Greene	.722
Hardin	.391
Hawkins	.706
Haywood	.701
Henry	.665
Knox	.541
Lawrence	.633
McNairy	.595
Madison	.480
Montgomery	.718
Obion	.716
Putnam	.670
Robertson	.587
Sumner	.516
Warren	.488
Weakley	.673
Williamson	.543
<u>Cotton</u>	
Bedford	.171
Carroll	.111
Chester	.196
Crockett	.296
Decatur	.221
Dyer	.112
Fayette	.324
Franklin	.096
Gibson	.142

TABLE XVI (continued)

County	Coefficient of Determination
Hardin	.339
Haywood	.239
Henderson	.131
Henry	.109
Lake	.000
Lauderdale	.130
Lincoln	.112
McNairy	.225
Madison	.243
Obion	.063
Rutherford	.014
Shelby	.108
Tipton	.149
<u>Tobacco</u>	
Claiborne	.772
Cocke	.864
Grainger	.792
Greene	.902
Hamblen	.701
Hancock	.791
Hawkins	.869
Jefferson	.800
Johnson	.848
Macon	.827
Maury	.758
Robertson	.913
Sevier	.715
Smith	.846
Sullivan	.924
Sumner	.917
Trousdale	.873
Washington	.935
Williamson	.815
Wilson	.791

regressions due to a lower degree of technological fit. Interpretation of county yield estimates must, however, be in terms of what portion of the nontechnological variation is influenced by drought variation.

Corn Data

Twenty-five counties were selected for analysis in this study. These counties accounted for greater than one-half of the estimated corn crop in 1970 and were considered to be the primary corn producing counties. Results of the regressions of drought-days against yearly corn production estimates can be seen in Table XVII.

In general, results from these analyses did not follow the expected pattern exhibited in the variety trial analyses. Coefficients of determination exhibited no consistent pattern from location to location, nor from region to region. If one assumes that the eastern portion of the state has generally less moisture stress than does the western section then the coefficients for the western counties would be expected to be greater than those of the eastern area. This was not the case. Neither was there a discernable pattern along latitudinal lines. It can be stated, however, that of that portion of yield variation not accounted for by trend the role of moisture status accounted for at least half of the variation.

Cotton Data

Twenty-two counties were analyzed for drought relationships. These counties were those evaluated in the cooperative Cotton Research Program

TABLE XVII

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF COUNTY CORN
YIELD ESTIMATES AGAINST WEEKLY DROUGHT-DAY TOTALS AS
CALCULATED BY THE THORNTHWAITE METHOD
FOR 25 COUNTIES

Moisture Status inches	Yield R^2	Yield Index R^2
<u>Benton</u>		
1	.092	.910
2	.321	.620
3	.156	.656
4	.284	.400
5	.287	.402
7	.146	.460
10	.078	.148
<u>Bledsoe</u>		
1	.559	.629
2	.460	.592
3	.547	.561
4	.371	.630
5	.341	.419
7	.336	.443
10	N.R.	N.R.
<u>Carroll</u>		
1	.136	.525
2	.500	.633
3	.367	.885
4	.211	.497
5	.180	.587
7	.350	.362
10	.258	.385
<u>Coffee</u>		
1	.434	.793
2	.419	.676
3	.365	.721
4	.186	.239
5	.161	.298
7	.110	.311
10	N.R.	N.R.

TABLE XVII (continued)

Moisture Status inches	Yield R^2	Yield Index R^2
<u>Cumberland</u>		
1	.697	.781
2	.633	.531
3	.346	.221
4	.197	.444
5	.185	.092
7	.051	N.R.
10	N.R.	N.R.
<u>Fayette</u>		
1	.337	.209
2	.504	.305
3	.341	.238
4	.144	.334
5	.088	.466
7	.066	.482
10	.072	.159
<u>Franklin</u>		
1	.493	.589
2	.763	.760
3	.479	.581
4	.366	.423
5	.185	.084
7	.211	.465
10	.250	.165
<u>Gibson</u>		
1	.300	.489
2	.432	.516
3	.332	.877
4	.174	.273
5	.142	.280
7	.218	.335
10	.243	.282
<u>Greene</u>		
1	.141	.244
2	.118	.413
3	.146	.531

TABLE XVII (continued)

Moisture Status inches	Yield R^2	Yield Index R^2
4	.339	.635
5	.148	.573
7	.058	N.R.
10	N.R.	N.R.
<u>Hardin</u>		
1	.094	.445
2	.147	.634
3	.133	.386
4	.130	.283
5	.169	.272
7	.133	.260
10	.371	.506
<u>Haywood</u>		
1	.194	.605
2	.851	.408
3	.120	.255
4	.117	.280
5	.253	.375
7	.127	.246
10	.092	.199
<u>Hawkins</u>		
1	.575	.390
2	.304	.526
3	.215	.350
4	.215	.544
5	.254	.771
7	.112	.191
10	N.R.	N.R.
<u>Henry</u>		
1	.071	.715
2	.083	.568
3	.132	.633
4	.224	.581
5	.240	.567
7	.340	.494
10	.106	.328

TABLE XVII (continued)

Moisture Status inches	Yield R^2	Yield Index R^2
<u>Knox</u>		
1	.117	.770
2	.155	.742
3	.160	.722
4	.282	.766
5	.304	.642
7	.373	.427
10	.010	.114
<u>Lawrence</u>		
1	.129	.766
2	.132	.197
3	.136	.669
4	.170	.422
5	.219	.611
7	.061	.156
10	N.R.	N.R.
<u>McNairy</u>		
1	.152	.705
2	.130	.557
3	.471	.522
4	.204	.465
5	.230	.311
7	.142	.156
10	.136	.146
<u>Madison</u>		
1	.330	.624
2	.177	.539
3	.164	.336
4	.316	.488
5	.375	.443
7	.123	.383
10	.104	.328
<u>Montgomery</u>		
1	.075	.585
2	.116	.581
3	.112	.400

TABLE XVII (continued)

Moisture Status inches	Yield R^2	Yield Index R^2
4	.159	.563
5	.129	.536
7	.114	.646
10	.060	N.R.
<u>Obion</u>		
1	.363	.436
2	.408	.254
3	.204	.146
4	.228	.215
5	.323	.243
7	.136	.088
10	.140	N.R.
<u>Putnam</u>		
1	.160	.634
2	.214	.481
3	.212	.526
4	.194	.494
5	.219	.328
7	N.R.	N.R.
10	N.R.	N.R.
<u>Robertson</u>		
1	.695	.650
2	.458	.680
3	.660	.619
4	.410	.803
5	.406	.820
7	.582	.758
10	.155	N.R.
<u>Sumner</u>		
1	.173	.106
2	.695	.430
3	.442	.256
4	.409	.276
5	.311	.173
7	.525	.237
10	.083	N.R.

TABLE XVII (continued)

Moisture Status inches	Yield R ²	Yield Index R ²
<u>Warren</u>		
1	.288	.554
2	.540	.394
3	.197	.472
4	.228	.474
5	.225	.292
7	N.R.	N.R.
10	N.R.	N.R.
<u>Weakley</u>		
1	.430	.697
2	.173	.846
3	.229	.446
4	.124	.428
5	.157	.540
7	.085	.190
10	.060	.236
<u>Williamson</u>		
1	.514	.651
2	.777	.516
3	.494	.477
4	.452	.606
5	.422	.639
7	.265	.409
10	.046	N.R.

and were considered to be the primary cotton producing counties in the state. Unlike data for corn and tobacco, the trend analyses for these counties were generally low (Table XVI, page 65) averaging 16 percent. Results of regressions of county cotton yield estimates against drought-days are in Table XVIII.

As with the corn analyses these data did not produce a discernable pattern within moisture bases for each location. A latitude-dependent trend was not apparent from examination of the values. Low R^2 values for index regressions in some counties are partly attributed to use of bottomlands where soil moisture storage is great or to supplementary irrigation which lessens moisture deficit and its effects.

Tobacco Data

Twenty tobacco producing counties were analyzed in this study. These counties were selected because together they produced over one-half of the estimated burley crop in 1970. Trend analysis of these counties revealed the closest fit to linearity of any of the three crops. Each county trend was greater than 70 percent linear with Washington County having a 93 percent linear crop yield advancement (Table XVI, page 65). Regressions of yield index against drought-days produced values of R^2 which indicated that moisture status was a relatively important component of the nontechnological yield variation (Table XIX). Further interpretation of these results proved futile as there was no general trend within sites or among all sites.

TABLE XVIII

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF COUNTY COTTON
YIELD ESTIMATES AGAINST WEEKLY DROUGHT-DAY TOTALS AS
CALCULATED BY THE THORNTHWAITE METHOD
FOR 22 COUNTIES

Moisture Status inches	Yield R^2	Yield Index R^2
<u>Bedford</u>		
1	.724	.822
2	.210	.612
3	.203	.160
4	.088	N.R.
5	.068	.068
7	.078	N.R.
10	.091	.055
<u>Carroll</u>		
1	.280	.524
2	.782	.638
3	.694	.732
4	.084	.099
5	.064	.064
7	N.R.	N.R.
10	.049	N.R.
<u>Chester</u>		
1	.291	.420
2	.386	.429
3	.430	.569
4	.386	.350
5	.340	.356
7	.201	.164
10	.063	N.R.
<u>Crockett</u>		
1	.350	.485
2	.381	.480
3	.198	.443
4	.232	.592
5	.245	.232
7	.217	.225
10	.258	.265

TABLE XVIII (continued)

Moisture Status inches	Yield R^2	Yield Index R^2
<u>Decatur</u>		
1	.465	.084
2	.221	.091
3	.113	.102
4	.089	.074
5	.049	.072
7	.080	.075
10	.155	.132
<u>Dyer</u>		
1	.457	.874
2	.230	.518
3	.688	.758
4	.378	.458
5	.485	.465
7	.087	.090
10	.054	N.R.
<u>Fayette</u>		
1	.224	.396
2	.420	.463
3	.340	.438
4	.353	.265
5	.358	.301
7	.334	.184
10	.051	N.R.
<u>Franklin</u>		
1	.769	.581
2	.228	.224
3	.232	.246
4	.157	.147
5	.155	.170
7	.166	.162
10	.112	.074
<u>Gibson</u>		
1	.143	.486
2	.186	.796
3	.667	.699

TABLE XVIII (continued)

Moisture Status inches	Yield R ²	Yield Index R ²
4	.072	.088
5	N.R.	N.R.
7	N.R.	N.R.
10	N.R.	N.R.
<u>Hardin</u>		
1	.262	.434
2	.188	.273
3	.333	.528
4	.228	.231
5	.323	.388
7	.312	.147
10	N.R.	N.R.
<u>Haywood</u>		
1	.318	.345
2	.586	.441
3	.213	.422
4	.247	.225
5	.249	.238
7	.222	.215
10	.259	.261
<u>Henderson</u>		
1	.102	.119
2	.260	.132
3	.098	.095
4	.102	.087
5	.069	.093
7	.086	.084
10	.162	.146
<u>Henry</u>		
1	.090	.089
2	.281	.398
3	.307	.060
4	.241	.186
5	.408	.062
7	.084	.066
10	N.R.	N.R.

TABLE XVIII (continued)

Moisture Status inches	Yield R^2	Yield Index R^2
<u>Lake</u>		
1	.796	.796
2	.114	.115
3	.167	.167
4	.138	.138
5	.149	.146
7	.082	.081
10	.058	.056
<u>Lauderdale</u>		
1	.246	.456
2	.163	.191
3	.125	.124
4	.139	.134
5	.154	.122
7	.197	.205
10	.606	.639
<u>Lincoln</u>		
1	.774	.806
2	.172	.183
3	.388	.208
4	.144	.123
5	.159	.129
7	.197	.121
10	.123	.082
<u>McNairy</u>		
1	.239	.334
2	.267	.104
3	.060	.084
4	.056	.204
5	.076	.204
7	N.R.	.078
10	N.R.	.053
<u>Madison</u>		
1	.544	.178
2	.355	.362
3	.442	.346

TABLE XVIII (continued)

Moisture Status inches	Yield R ²	Yield Index R ²
4	.181	.406
5	.127	.206
7	.151	.181
10	.212	.341
<u>Obion</u>		
1	.471	.397
2	.150	.107
3	.128	.253
4	.419	.266
5	.120	.097
7	.096	.075
10	.092	.063
<u>Rutherford</u>		
1	.400	.391
2	.546	.564
3	.450	.450
4	.481	.106
5	.087	.077
7	.102	.100
10	.089	.081
<u>Shelby</u>		
1	.240	.436
2	.098	.109
3	N.R.	.067
4	N.R.	N.R.
5	N.R.	N.R.
7	.060	N.R.
10	.054	N.R.
<u>Tipton</u>		
1	.352	.352
2	.178	.213
3	.162	.164
4	.314	.293
5	.298	.148
7	.472	.228
10	.586	.622

TABLE XIX

COEFFICIENTS OF DETERMINATION FROM REGRESSIONS OF COUNTY BURLEY
TOBACCO YIELD ESTIMATES AGAINST WEEKLY DROUGHT-DAY TOTALS AS
CALCULATED BY THE THORNTHWAITE METHOD
FOR 20 COUNTIES

Moisture Status inches	Yield R^2	Yield Index R^2
<u>Claiborne</u>		
1	.160	.610
2	.611	.445
3	.220	N.R.
4	.485	N.R.
5	.494	N.R.
7	N.R.	N.R.
10	N.R.	N.R.
<u>Cocke</u>		
1	.644	.207
2	.413	.242
3	.325	.324
4	.062	.288
5	.074	.351
7	.098	.163
10	.059	.159
<u>Grainger</u>		
1	.747	.419
2	.544	.111
3	.672	.110
4	.655	.096
5	.435	.149
7	.374	.122
10	.066	N.R.
<u>Greene</u>		
1	.918	.642
2	.440	.268
3	.686	.226
4	.451	.202
5	.408	.424
7	.273	.531
10	N.R.	N.R.

TABLE XIX (continued)

Moisture Status inches	Yield R ²	Yield Index R ²
<u>Hamblen</u>		
1	.764	.349
2	.415	.230
3	.688	.662
4	.492	.622
5	.556	.528
7	.473	.273
10	N.R.	N.R.
<u>Hancock</u>		
1	.431	.086
2	.259	N.R.
3	.267	.059
4	.267	N.R.
5	.304	.061
7	.393	.351
10	N.R.	N.R.
<u>Hawkins</u>		
1	.800	.878
2	.414	.085
3	.375	.096
4	.375	.114
5	.442	.188
7	.435	.558
10	N.R.	N.R.
<u>Jefferson</u>		
1	.291	.470
2	.207	.303
3	.602	.281
4	.686	.264
5	.476	.253
7	.413	.246
10	.094	N.R.
<u>Johnson</u>		
1	.545	.388
2	.914	.331
3	.441	.439

TABLE XIX (continued)

Moisture Status inches	Yield R^2	Yield Index R^2
4	.446	.259
5	.133	.209
7	.122	.108
10	N.R.	N.R.
<u>Macon</u>		
1	.656	.926
2	.543	.626
3	.553	.743
4	.379	.654
5	.338	.531
7	.100	.414
10	N.R.	N.R.
<u>Maury</u>		
1	.280	.594
2	.338	.347
3	.236	.381
4	.252	.388
5	.373	.368
7	.346	.324
10	.224	.245
<u>Robertson</u>		
1	.971	.564
2	.458	.185
3	.205	.164
4	.195	.153
5	.193	.148
7	.483	.119
10	.162	.151
<u>Sevier</u>		
1	.371	.535
2	.200	.577
3	.078	.381
4	.076	.188
5	.076	.194
7	N.R.	N.R.
10	N.R.	N.R.

TABLE XIX (continued)

Moisture Status inches	Yield R ²	Yield Index R ²
<u>Smith</u>		
1	.478	.250
2	.192	.395
3	.302	.700
4	.607	.389
5	.230	.164
7	N.R.	.164
10	N.R.	N.R.
<u>Sullivan</u>		
1	.415	.280
2	.941	.330
3	.729	.192
4	.282	.169
5	.318	.489
7	.209	N.R.
10	.096	N.R.
<u>Sumner</u>		
1	.893	.449
2	.562	.359
3	.380	.170
4	.704	.328
5	.401	.124
7	.644	.077
10	.321	.010
<u>Trousdale</u>		
1	.714	.698
2	.161	.986
3	.384	.480
4	.113	.428
5	.317	.281
7	.084	.160
10	N.R.	N.R.
<u>Washington</u>		
1	.918	.539
2	.419	.219
3	.836	.448

TABLE XIX (continued)

Moisture Status inches	Yield R^2	Yield Index R^2
4	.524	.426
5	.422	.820
7	.227	.666
10	N.R.	N.R.
<u>Williamson</u>		
1	.314	.417
2	.259	.401
3	.416	.633
4	.336	.273
5	.418	.352
7	.358	.416
10	.140	.144
<u>Wilson</u>		
1	.197	.149
2	.355	.581
3	.230	.127
4	.345	.137
5	.271	.160
7	.274	.326
10	.470	.519

V. GENERAL DISCUSSION

Ability of plants to withstand moisture deficit stress can rely on one or more of these factors: (1) avoidance of deficit periods by alteration of life cycle; (2) increased rooting depth thereby effectively increasing soil moisture availability; and (3) biochemical adaptation which increases water-use efficiency. These strategies are the results of selection processes in the area of origin of these plants, yet they may or may not be of benefit when plants are grown outside that area. The first strategy is not a point of consideration in this study in that all crops are grown during periods of moisture deficit in Tennessee. The third strategy is of advantage to corn to the extent that its water-use efficiency (dry matter produced per gram of water evaporated and transpired) is greater than that of either cotton or tobacco. However, in terms of drought stress as established in this work, relative efficiencies may or may not be critical. Rooting depth, the second strategy, is critical to the ultimate effect of soil moisture depletion on yields of any crop or the growth of any plant.

Long (21) examined rooting depths and root weight of several crop species in Tennessee. He found that mature cotton roots in a well drained soil had 57.3 percent of their oven-dry weight in the topmost six inches of profile. Approximately 80 percent of root weight was found in the upper 16 inches of the solum. Overall rooting depth of cotton in his study was 32 inches.

Long found 69.0 percent of the oven-dry weight of corn roots were located in the upper six inches of a well drained soil. Rooting depth was 33 inches; however, the majority of roots were located in the plow layer. Approximately 86.6 percent of the root weight was located within the topmost 15 inches of the soil. Long performed one root study with burley tobacco. He measured a maximum rooting depth of 32 inches with 79 percent of the root biomass in the surface five inches. Ninety-six percent of the roots were found in the upper 12 inches of soil.

Relating these data to the yield analyses discussed earlier, it is evident that these crops are subject to critical drying of the rhizosphere during their growing season. Yield variation itself points to these effects. If one considers an average available water holding capacity within the effective rooting depth to be about 3.2 inches of water for conditions in western Tennessee and on the loess covered soils of the Highland Rim and about 2.5 inches of water for the more clayey soils of the Central Basin, Highland Rim, and eastern Tennessee, then one can look at the yield index regressions for further interpretation of significant stress periods.

At Knoxville, corn yields were affected by deficits occurring during three periods. The first period occurred from the middle of May to the middle of June (weeks 12 through 16), the first week in July (week 18), and the period from the last of July through the month of August (weeks 22 through 27). These periods roughly coincided with the time of germination and initial establishment, the period prior to

anthesis, and the period of grain filling. Greeneville corn yield variations were sensitive to deficits from June 1 through July 12 and from July 26 through August. These periods were approximately the period prior to anthesis and the period of grain-set. Crossville corn variety trial yields were sensitive primarily at one period, July 26 through August 15 (weeks 22 through 26) which was approximately the period of anthesis. Data from Springfield indicate significant effects through most of the growing season; a similar condition was apparent at Spring Hill. Jackson yields exhibited two periods of significant response to drought (weeks 15, 17, and 19 through 20), during vegetative growth and prior to tasseling. Drought stress during grain filling contributed significantly to yield variation there (weeks 22 through 24 and week 27). These data were in general agreement with Slatyer (36), Denmead and Shaw (12), and Odell (25). Odell reported that 58 percent of corn yield variation in Illinois was explained by climatic environment between May 20 and August 23 (weeks 12 through 23). Denmead and Shaw, working with corn in the greenhouse, observed a 25 percent yield reduction if stress (to the wilting point) was applied prior to silking; stress at silking reduced yields by 50 percent; and stress applied after silking reduced yields by 21 percent.

Periods critical for cotton yield fluctuation were roughly the same for all four locations. Deficits occurring from June 7 through July 18 and from August 2 through September 5 were significant to yield fluctuations. Cotton has an indeterminate growth pattern and continues to flower over an extended period. This somewhat protects the plant from

isolated periods of stress. The role of moisture regime was more significant at both Fort Pillow and at Ames Plantation than at either Jackson or Knoxville in terms of magnitude of the R^2 .

Tobacco yields at the four locations varied with significant deficits occurring from the first of July through August. Magnitude of coefficients of determination indicated that deficits at Rutledge contributed less to yield variation than did other factors. Drought at Spring Hill accounted for more variation in production than at any other location studied.

Analyses of county yield estimates indicated that moisture deficit does play a role in these production figures; however, due to the extreme linearity of yield trends and to the formulation of these averages, further interpretation was considered inappropriate. The degree of linearity of the raw yield estimates made accurate application of these data extremely tenuous.

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CHAPTER IV

SUMMARY AND CONCLUSIONS

Delineation of the general effects of drought on crops in Tennessee and the critical periods during which crop yields are significantly affected had not been performed for Tennessee. Purposes of this study were:

1. To calculate drought-days using evapotranspiration values derived from four water-use models;
2. To evaluate each model by application to variety trial yields of corn, cotton, and burley tobacco varieties from several locations in the state;
3. To select the best model for use under Tennessee conditions and to calculate drought probabilities from those data; and
4. To evaluate county yield estimates in terms of their response to drought-days as calculated by the best model.

Evapotranspiration values were calculated using the methods described by Penman, Blaney-Criddle, and Thornthwaite; drought-days were calculated using these values and were summed by climatic weeks and by calendar months. An adjusted Thornthwaite method developed by Wiser and van Schilfgaarde (49) which only calculated drought-days on a monthly basis was also evaluated.

Crop yield variation proved to be most sensitive to drought calculated using Thornthwaite-derived evapotranspiration values. Crop

response to Blaney-Criddle-derived drought was intermediate, while the yield variation response to Penman-derived values indicated that the latter method was least sensitive to prevailing conditions. Drought totals per month as calculated by the Wiser modification as well as monthly totals from the Thornthwaite equation proved to be less sensitive to actual conditions as reflected in crop yield than did weekly totals of drought-days. This was primarily due to the masking of within-month variation of moisture status which was more precisely revealed by weekly drought-day totals. Relative lack of predictive power of Penman-derived drought totals was attributed to the complexity of the formula and the lack of truly adequate data from many locations within Tennessee. Regressions of weekly drought-day totals against variety trial yields indicated that critical periods for corn growth occurred primarily during germination, during anthesis, and during grain-filling. Weekly periods critical for cotton yield were approximately the same for all West Tennessee locations; however, moisture stress was more significant at Fort Pillow and Ames Plantation than at Jackson or Knoxville. Tobacco yields varied with significant deficits occurring from the first of July through August. In general, for all crops, stress at almost any stage between floral initiation and maturity was likely to result in yield variation. At those general levels of available water within the effective rooting zone it appeared that the preflowering stage was the most tolerant to moisture deficit; however, drought at flowering and during maturation were the primary causes of yield reduction and/or variation.

Probabilities of drought occurrence were calculated using Thornthwaite ET values for each of the 50 selected locations (32).

Analyses of county yield estimates indicated that moisture status does play a role in production; however, due to extreme linearity of these yield estimates and to the nature of their derivation no further interpretation was considered appropriate.



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APPENDIX

TABLE XX
AVAILABILITY OF VARIETY TRIAL DATA FOR CORN

Year	Location*							
	A	B	C	D	E	F	G	H
1947	X	X	X	X	X	X		
1948	X	X	X	X	X	X		
1949	X	X	X	X	X	X		
1950	X	X	X		X	X		
1951	X	X	X	X	X	X		
1952								
1953	X	X	X	X	X	X		
1954								
1955	X	X	X	X	X	X	X	
1956	X	X	X	X	X	X	X	
1957								
1958		X			X	X	X	
1959	X	X	X	X			X	
1960	X	X	X	X		X		
1961	X	X	X	X	X	X		
1962	X	X	X	X	X	X		X
1963	X	X	X	X	X	X		X
1964	X	X	X	X	X	X		X
1965	X	X	X	X	X	X		X
1966	X		X	X	X	X	X	X
1967	X	X	X	X	X	X	X	X
1968	X	X	X	X	X	X	X	X
1969	X	X	X	X	X	X	X	X
1970	X	X	X	X	X	X	X	X

* A-Greeneville
B-Knoxville
C-Crossville

D-Springfield
E-Spring Hill
F-Jackson

G-Fort Pillow
H-Martin

TABLE XXI
 AVAILABILITY OF VARIETY TRIAL DATA FOR COTTON

Year	Location*						
	A	B	C	D	E	F	G
1949				X	X		X
1950		X		X	X		X
1951							
1952							
1953		X		X	X		X
1954							
1955	X	X	X	X	X		X
1956	X	X	X	X	X		X
1957	X		X	X	X	X	
1958	X		X	X	X		X
1959	X			X	X		X
1960	X		X	X			X
1961				X			X
1962	X			X			X
1963	X		X	X			X
1964	X		X	X			X
1965	X		X	X			X
1966	X		X	X			X
1967	X		X	X		X	
1968	X		X	X		X	
1969	X			X		X	
1970	X		X	X		X	

* A-Fort Pillow
 B-Tiptonville
 C-Ames Plantation

D-Jackson
 E-Lawrenceburg

F-Milan
 G-Knoxville

TABLE XXII
 AVAILABILITY OF VARIETY TRIAL DATA FOR BURLEY TOBACCO

Year	Location*			
	A	B	C	D
1957	X	X	X	X
1958	X	X	X	X
1959	X	X	X	X
1960	X	X	X	X
1961	X	X	X	X
1962	X	X	X	X
1963	X	X	X	X
1964	X	X	X	X
1965	X	X	X	X
1966	X	X	X	
1967	X		X	X
1968	X	X	X	X
1969	X	X	X	
1970	X	X	X	X

* A-Greeneville
 B-Rutledge

C-Springfield
 D-Spring Hill

TABLE XXIII
CLIMATIC WEEKS AND CODED EQUIVALENTS USED IN REGRESSIONS

Code	Climatic Week		Code	Climatic Week	
X1	March	1	X27	August	30
X2		8	X28	September	6
X3		15	X29		13
X4		22	X30		20
X5		29	X31		31
X6	April	5	X32	October	4
X7		12	X33		11
X8		19	X34		18
X9		26	X35		25
X10	May	3	X36	November	1
X11		10	X37		8
X12		17	X38		15
X13		24	X39		22
X14		31	X40		29
X15	June	7	X41	December	6
X16		14	X42		13
X17		21	X43		20
X18		28	X44		27
X19	July	5	X45	January	3
X20		12	X46		10
X21		19	X47		17
X22		26	X48		24
X23	August	2	X49		31
X24		9	X50	February	7
X25		16	X51		14
X26		23	X52		21

VITA

John Marcus Safley, Jr., was born January 4, 1947, in Milan, Gibson County, Tennessee. He attended elementary schools in Woodbury and Nashville, Tennessee, and graduated from Hillwood High School, Nashville, in June, 1964. He entered Vanderbilt University where he received the Bachelor of Arts degree with a major in general biology in June, 1968. While enrolled he was employed three summers as laboratory assistant in the Pharmacology Department of the Vanderbilt Medical School. After graduation he was employed as herbarium assistant for the Vanderbilt Biology Department.

He entered the Graduate School of the University of Tennessee, Knoxville in September, 1968. He received a Graduate Fellowship from the U. S. Army Corps of Engineers for 1969-1970 to complete his research. Mr. Safley received the Master of Science degree with a major in botany in December, 1970.

In September, 1970, he was accepted as a Graduate Research Assistant in the Plant and Soil Science Department of the University of Tennessee. He received the Doctor of Philosophy degree with a major in Plant and Soil Science in August, 1974. He is a member of Gamma Sigma Delta, Sigma Xi, Phi Sigma, the American Society of Agronomy, the Crop Science Society of America, the Association of Southeastern Biologists, and the American Institute of Biological Sciences.