Scheduling and Application Rates of Irrigation in a Humid Climate

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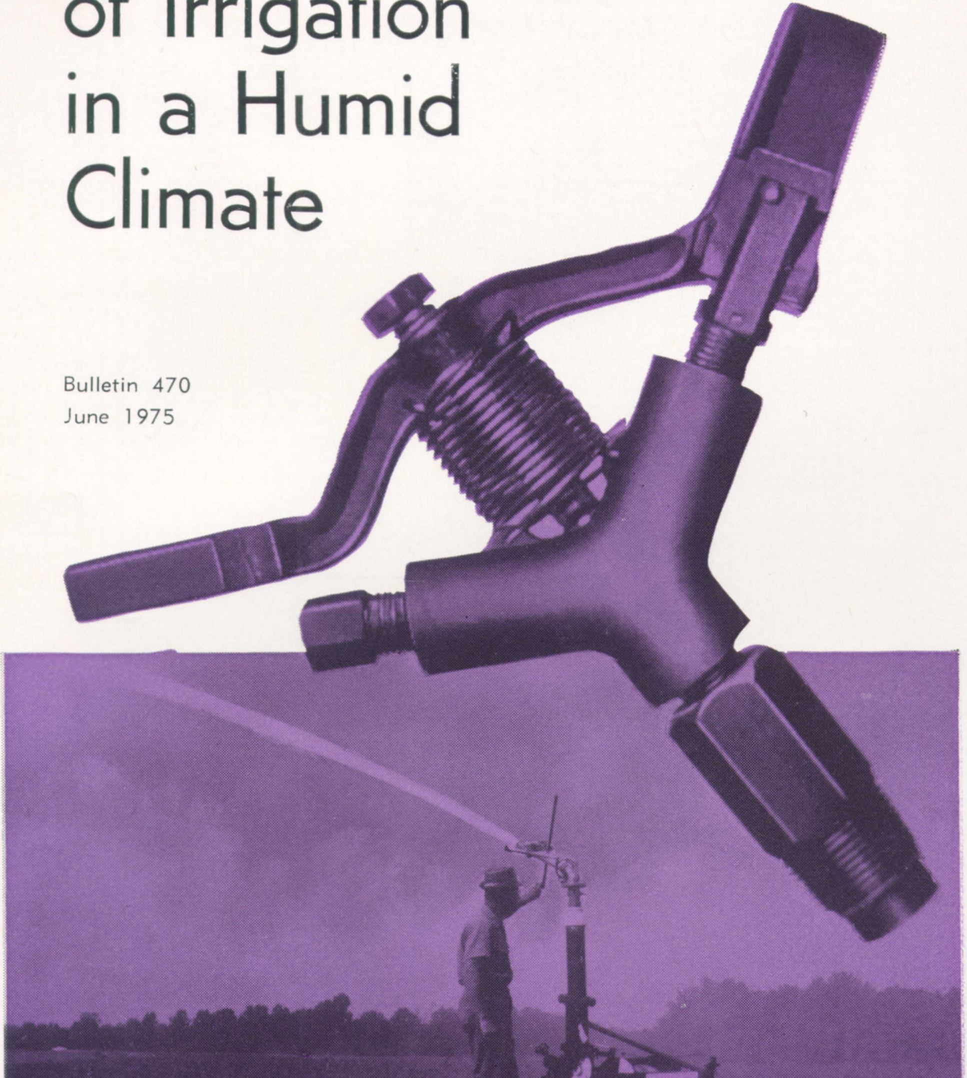

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SUMMARY

A 4-year study of irrigation scheduling methods and application rates was conducted to determine more efficient uses of supplemental water. Two scheduling models were tested. One model based the decision to irrigate on weather forecasts and soil moisture conditions; the other, irrigation by demand, based the irrigation decision only on soil moisture conditions. Application rates of 0.13 inches per hour (low) and 0.43 or 0.7 inches per hour (high) were tested to determine the suitability of low application rate sprinkling in a humid climate.

A computer program was developed to calculate soil moisture and predict irrigation needs in the forecast scheduling model. A probability of rainfall occurrence greater than 0.5 inch was the acceptance level for including a rainfall event. The weather forecast also provided the basis of deciding how much rainfall would be included in the soil moisture balance.

After 3 years of field tests, growing cotton on a sandy loam soil, no advantage could be ascertained from the inclusion of weather forecasts. However, irrigation in itself did improve yields significantly over non-irrigated yields. The better treatment, irrigation by demand, increased production 160 pounds of seed cotton per acre for each inch of water applied with an average of 6.3 inches applied each year. Simulation studies following the field experiments indicated that the reduction in moisture excesses as a result of the use of forecasts was insignificant but that moisture deficits were significantly greater than those in the demand model.

In the associated application rate study the low application rate of 0.13 inches per hour was found to be superior in cotton production and in the minimization of soil crust strength. The study also suggested that an exponential relation is appropriate for relating crust strength to crust moisture content.

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SCHEDULING and APPLICATION RATES of IRRIGATION in a HUMID CLIMATE

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INTRODUCTION

IN A PERIOD of drought there are generally greater than normal demands for water application and at the same time there are diminished supplies of water available. Therefore, scheduling water applications for optimizing crop growth and assuring efficient water use has been given high priority, especially in arid areas.

Computer programs that can predict approximate irrigation dates have proved invaluable. One group of researchers (Jensen, et al., *(7)*) developed a computer program for irrigation scheduling under arid-climate conditions. Their program has been field tested for several years in Arizona and Idaho. The program calculates evapotranspiration from solar-radiation data and crop-related factors, adds rainfall amounts and calculates the soil-moisture depletion. Updated calculations are made twice each week. The irrigator is given a bi-weekly report which informs him of the approximate number of days before an irrigation is needed and also suggests the amount of water to apply at that time.

Other studies have demonstrated the usefulness of correlating plant-water use with evaporation from a free-water surface. Jensen and Middleton *(6)* have shown a nearly constant relationship between the rate of evaporation by a crop and the rate of evaporation from a Weather Service Class A Pan. Others, in-

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cluding Hargreaves *(5)* and Shahin *(14)* have presented crop coefficient curves relating evapotranspiration to pan evaporation.

A calculated risk model for Southeastern use has been developed by Allen and Lambert *(1)*. Daily irrigation decisions are based on 24-hour rainfall probabilities, irrigation costs and potential crop damage resulting from inadequate soil-moisture. The calculated risk model is limited, however, by the absence of data on dollar loss which can be assigned to any individual or series of omitted water applications. Using a previous year's weather records, the calculated risk model showed the possibility of saving water when compared to irrigating by soil-moisture criteria.

The irrigation scheduling approaches which have been cited combine past weather records with soil and plant data for determining when to irrigate. In addition, Allen and Lambert *(1)* also incorporated rainfall probabilities. The research reported herein presents a scheduling model which not only incorporates forecasts in an attempt to economize supplemental water usage, but also incorporates a multi-field scheduling of irrigation equipment. The results of this scheduling model are compared to the results of a demand schedule in which water is applied to the crop as required assuming no equipment limitations.

This report also presents results of a comparison of two application rates upon the efficiency of water use and upon crusting of the soil surface. Numerous studies have been made to define factors influencing crust formation. Prior research has shown that crust strength increases with increasing rainfall amounts, Carnes *(3)*, and increasing rates of water application, Mantel and Goldberg *(10)*, and that it decreases with increased numbers of wetting and drying cycles, Lemos and Lutz *(9)*. Investigations to determine the effect of sprinkler intensities and repeated applications upon crust strength have not been previously reported.

Design criteria dictate that the rate of water application be maintained slightly below the soil intake rate. However, sprinkler irrigation research in other regions, Gray *(4)* and Keller *(8)*, has demonstrated that a low rate of application, on the order of 0.1 to 0.2 inches per hour, results in better soil structure and a reduction in compaction when compared with high application rates. Stegman et al., *(15)* demonstrated that the percent saturation in the soil decreases exponentially as the application rate decreases. Thus, short periods of oxygen deficiency that have been found to reduce growth and yields of crops are reduced or eliminated with lower application rates.

Although the low application rate concept has been adopted in drier climates it has not been fully investigated in regions where natural rainfall provides most of the water for plant growth.

IRRIGATION SCHEDULING

Irrigation Policy

An irrigation policy consists of a set of guidelines relating to irrigation timing and amount, and is developed prior to the growing season. The policy must appropriately reflect the type system in use and the desired results. In this study systems under consideration are restricted to those which are portable to the extent that water can be applied to several sectors of land during different time periods. Examples of these type systems include hose-pull travelers and center pivots as well as portable lateral systems. Portability allows the producer freedom to subdivide land into more than one sector using the same equipment and moving it from location to location.

The number of sectors which can be irrigated with a system depends upon such factors as peak moisture use by the plants, application rate, and moisture holding capacity of the soil. For example, with a typical moisture usage of 0.3 inch per day and a moisture holding capacity in the root zone of 3 inches, a sector would have a 10-day supply of water. Following a typical policy to irrigate when one-half of the water has been removed would result in water applications every 5 days. Any number of sectors could be established. The use of 20 sectors would allow 6 hours irrigation time for each sector whereas the use of five sectors would allow 24 hours per irrigation. Longer irrigation times permit lower application rates.

Consideration of when to irrigate may be based on the value of any of several soil or plant parameters. The most widely used are soil-moisture content and soil-moisture tension. Moisture tension relates more closely with availability of moisture to the plant but moisture content is easier to manipulate. Since a functional relationship exists between the two for any given soil, moisture content may be used as a decision parameter without any loss of sensitivity. If moisture content is expressed as the percent of the available moisture, the lowest desirable moisture content may be selected at any level between 0 and 100 percent available moisture. Selecting a drier soil moisture level has the effect of delaying irrigations at the expense of increased stresses in the plant and possibly lower yields.

Moisture stresses of a given magnitude do not have the same effect during differing periods of growing season. Generally, crops are more adversely affected by stresses during flowering and become less sensitive to moisture stresses as the season ends. Therefore the more responsive irrigation policies vary desirable moisture levels as the season progresses.

Once the decision has been made to irrigate, then the policy must stipulate the amount to apply. Several alternative policies could be followed depending upon the objectives. If the overall objective is to minimize the number of irrigations at the increased risk of applying unneeded water the policy would be to apply enough water to return the soil moisture to field capacity. If the objective is to minimize supplemental water usage, then only enough water is applied to a sector to allow irrigation of all sectors and return to the initial sector prior to obtaining an undesired condition. Under this policy the soil is left drier allowing more potential storage of subsequent rainfall. Since the conservation of water is a major objective of this study, the policy of minimizing supplemental water usage was adopted.

Cotton, a major row crop for the Southeast, was selected as the test crop for field evaluation of the irrigation models under study. For this crop the minimum desired or critical available soil moisture (CAM) was selected to be 40 percent but was reduced in steps near the end of the season as shown in Figure 1. Also shown in Figure 1 are the 7-day supply (SDS) and the total available moisture (TAM) curves.

The field tests were conducted on a Dothan sandy loam soil which has an available moisture holding capacity of 1.3 inches per foot. Root depth measurements were made at regular intervals during the first year uniformity tests and were presented by Rochester and Busch *(12)*. At the maximum root depth of 3 feet, 3.9 inches of water are available for plant use. With the 40 percent policy, irrigation would be required when 2.3 inches of water has been removed from the soil. Since the maximum anticipated water usage by cotton is approximately 0.3 inch per day, the maximum time between water applications is 7 days. With a policy of irrigating one sector per day, a maximum of seven sectors could be established. However, a five-sector policy was estab-

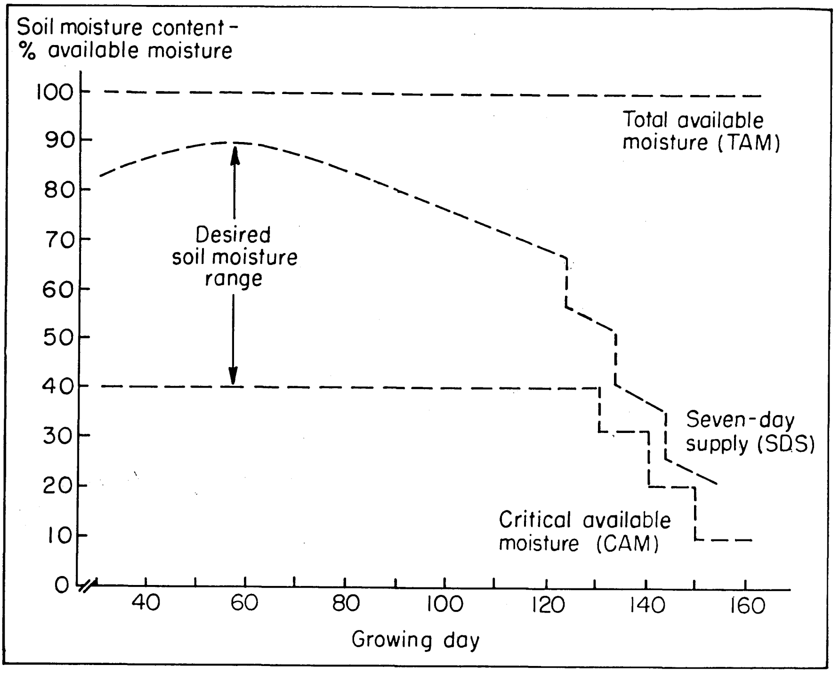

FIG. 1. Soil moisture boundaries for forecast and demand scheduling.

lished in order to allow some slack time in the irrigation schedule. This selection also eliminates the necessity to project moisture requirements beyond the U.S. Weather Bureau 5-day agricultural forecast.

Scheduling Models

The soil moisture condition of each sector was estimated during the growing season by assuming the soil to be initially at field capacity and then subtracting or adding moisture changes as described by equation (1).

$$AVM(I) = AVM(I\text{-}1) + PR(I\text{-}1) + SI(I\text{-}1) + DSM(I\text{-}1) - ET(I\text{-}1) \quad (1)$$

where:

I = Growing season day,
AVM = Available moisture,
PR = Precipitation,
SI = Sprinkler irrigation,
DSM = Daily soil moisture increase due to root growth,
and ET = Evapotranspiration.

Weather data required as inputs to equation (1) include precipitation and pan evaporation (which is used to calculate ET). These data were obtained from a weather station located near the field plots. The SI value is the actual amount applied to a sector during the previous day. The DSM value is the product of daily root growth and soil moisture capacity.

In addition to estimating daily soil moisture, the irrigation policy requires prediction of soil moisture for several days in advance because the soil moisture of several sectors must be maintained above the critical available moisture. For example, if all five sectors of the forecast model require irrigation on a given day, it would be necessary to begin irrigation 5 days in advance to avoid having any sector become too dry.

The equation for predicting the expected soil moisture is

$$\mathrm{XAM} = \mathrm{AVM} + \mathrm{XPR} + \mathrm{DSM} - \mathrm{ET} \qquad (2)$$

where:

XAM = Expected available moisture
and XPR = Expected precipitation.

Expected precipitation is obtained from 5-day agricultural forecasts. These forecasts give probabilities of rain for today, tonight, and tomorrow and the probable amounts. In addition, the third, fourth, and fifth day forecasts are given qualitatively. To quantify precipitation for the today, tonight, and tomorrow period, a combined probability for the time period in question is determined as described by Allen and Lambert *(1)*. When the combined probability is greater than 0.5 the forecast precipitation is added to the soil moisture prediction. Outlook forecasts require a greater degree of judgment based primarily on the forecast wording. Fortunately the effects of an unfulfilled forecast remains only 2 or 3 days in the scheduling since the next updating replaces the forecast with fact.

The estimate of future evapotranspiration is made by using records of average daily pan evaporation Mott *(11)* and appropriate pan-crop coefficients Shahin *(14)*. The use of average data tends to overestimate plant-water use when rain occurs and underestimate it during prolonged clear periods. However, errors do not accumulate since updating with the actual evaporation record replaces the estimate.

Scheduling Procedures

The forecast scheduling model is maintained by a computer program which is presented in the Appendix. At the beginning of a growing season, all seasonal information is placed in computer storage. This information includes root depths, crop coefficients, available moisture at field capacity, critical available moisture, assumed evapotranspiration, and the moisture increase attributable to root growth.

During the growing season available moisture and predicted available moisture are calculated for each of the five sectors regularly. A flow chart of the irrigation scheduling process is shown in Figure 2. The predictions of available moisture are made for each of the next 5 days. Where these moisture values fall below the critical moisture level, irrigation may be needed and is so indicated in the computer print-out. Appendix Table 5 gives an

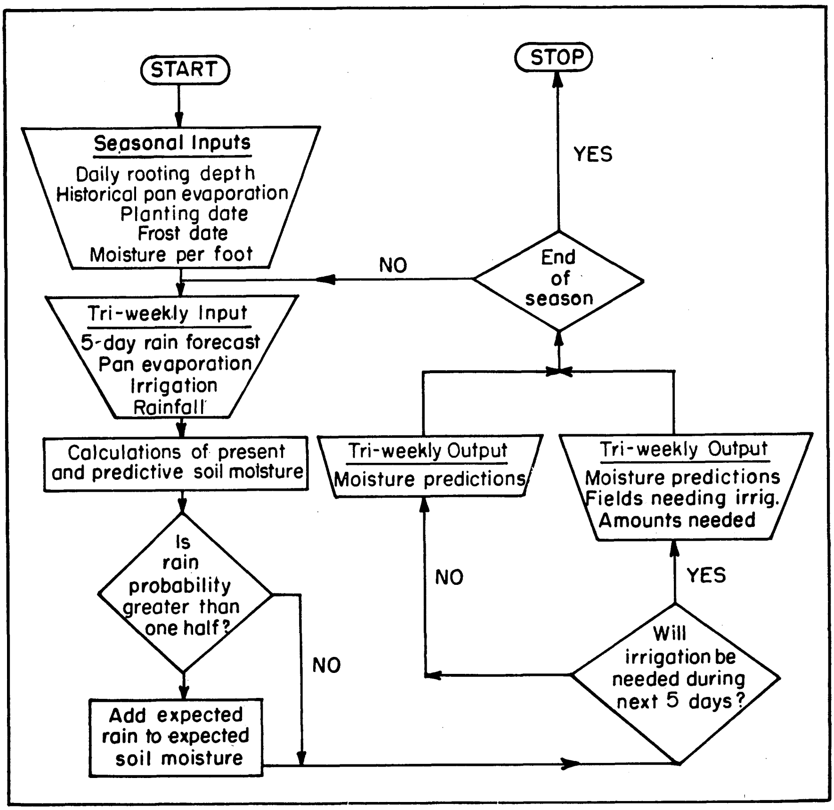

FIG. 2. Flow chart of irrigation scheduling process.

example where irrigation is indicated for day 5. If the outlook indicated that all five sectors would need irrigation 5 days hence, then irrigation would begin and continue so that 4 days hence only one field would need water. Of course, the intervening updating may change the predicted soil-moisture conditions.

The demand scheduling model incorporates only one sector with irrigation decisions based only on existing soil moisture. Thus, the decisions were made in the field without regard for other sectors or possible rainfall.

FIELD TESTS

Methods

Field evaluations of forecast and demand schedules and the two application rates were made during a 3-year period with replicated plot designs. Only two of the five sectors (nos. 1 and 4) of the forecast schedule were actually field evaluated even though all the sectors were scheduled in the computer model. The two treatments with varying application rates were scheduled by the demand model. The low application rate was selected to be 0.13 inch per hour, a value within the range of a nonsaturating water application. The high application rate of 0.7 inch per hour was selected to be below the intake rate of the sandy loam soil. Later observation of the high application rate irrigation indicated this value to be above the intake rate of the compacted soil and the value was subsequently lowered to 0.4 inch per hour for the last year of testing.

Soil moisture depletion of all plots was determined by readings taken from electrical resistance blocks located at 0.5, 1.5, and 2.5-foot depths. These values were integrated graphically over the rooting depth to obtain the average soil moisture. Soil moisture values obtained from the forecast scheduled plots were compared with values predicted by the model. In the event of significant variations, the model was corrected to more closely correspond with the field values. The average moisture readings obtained from the demand scheduled plots were used directly to make irrigation decisions.

The field tests, with cotton as the irrigated crop, were performed at the Agricultural Engineering Research Unit, Marvyn, Alabama for 3 successive years. The treatments on the sandy loam soil were randomized in three complete replications on 60-foot by 60-foot plots with the center eight rows sampled for crop yields. For comparison adjacent non-irrigated areas were also sampled in three replications each year.

Results

Success for the forecast scheduling model with sectors is dependent upon the capability to predict daily soil moisture. Therefore moisture estimations were regularly compared to soil moisture values as measured in the field. Moisture use estimations were made by multiplying pan evaporation values by a crop coefficient. During the early part of the 1971 growing season, use of the Hargreaves coefficient resulted in moisture usage predictions consistently higher than those measured, thus requiring several adjustments. These discrepancies were initially attributed to the poor stand of cotton obtained in 1971. Late year moisture usage resulted in better correlation of values.

Early in the 1972 growing season, discrepancies in moisture predictions again appeared despite a more uniform stand. A comparison of actual moisture usage to estimated usage made with several crop coefficients resulted in the selection of the Shahin *(14)* coefficient curve as being best suited for test conditions. Use of the Shahin coefficient curve improved moisture estimations but did not completely eliminate the necessity for adjustments. On the sixtieth day of the 1973 growing season, average field soil moisture was 1 inch drier than estimated and an adjustment was necessary. However, during most of the season, measurements and estimations were sufficiently close.

Table 1 presents the total yearly amount of supplemental water applied to each treatment. Although yearly ranking of moisture application is not consistent, the 3-year average indicates that forecast scheduling required less water than scheduling by de-

TABLE 1. TOTAL YEARLY SUPPLEMENTAL WATER APPLICATION

Treatment	Supplemental water application			
	1971	1972	1973	3-yr. av.
	In.	*In.*	*In.*	*In.*
Forecast schedule, low application rate and sectors[1]	4.9	7.7	5.0	5.9
Demand schedule, low application rate without sectors	5.0	9.3	4.5	6.3
Demand schedule, high application rate without sectors	6.5	7.2	6.6	6.8

[1] These figures are averages of sectors 1 and 4.

TABLE 2. YEARLY AND AVERAGE YIELDS OF TEST TREATMENT

Treatment	Yield seed cotton per acre[3]			
	1971	1972	1973	3-yr. av.
	Lb.	*Lb.*	*Lb.*	*Lb.*
Forecast schedule	3,099[1,2]	2,544[2]	2,711[2]	2,785
Demand schedule, low application rate	3,327[1]	2,892	2,765	2,995
Demand schedule, high application rate	3,025[1]	2,365	2,677	2,689
No irrigation	2,705[1]	1,177	1,877	1,920

[1] These figures are adjusted for plant skips resulting from a poor stand.
[2] These figures are averages of sectors 1 and 4.
[3] Varieties are Auburn 56 in 1971 and Deltapine 16 in 1972 and 1973.

mand. However, a comparison of yields in Table 2 indicates forecast schedule plots produced less cotton than demand schedule at the same low application rate. High application rate irrigation produced lower yields but were still significantly higher than adjacent nonirrigated cotton.

A more lucid comparison of treatments is shown in Table 3. Here the comparison of irrigation production efficiencies shows consistently that the demand schedule with low application irrigation outperformed the forecast schedule in term of pounds of cotton produced for each inch of water applied. High application rate irrigation was the least efficient user of supplemental water. The consistent tendency for the high application rate to produce runoff was the probable reason for this low efficiency.

The superiority of the demand schedule must be attributed to its capability to supply water at the appropriate time in comparison to the forecast schedule with sectors which, due to the equipment restriction, must necessarily water some sectors at less optimum times.

TABLE 3. INCREASE IN YIELD AS A RESULT OF IRRIGATION

Treatment	Irrigation production efficiency (seed cotton produced per acre per inch of water applied)			
	1971	1972	1973	3-yr. av.
	Lb.	*Lb.*	*Lb.*	*Lb.*
Forecast schedule, low application rate	80	142	169	130
Demand schedule, low application rate	125	155	200	160
Demand schedule, high application rate[1]	49	127	125	100

[1] The 1971 and 1972 high application rate of 0.7 in./hr. resulted in excess runoff and was reduced to 0.4 in./hr. for the 1973 growing season.

SIMULATED COMPARISON OF SCHEDULES

Since the field tests were used to compare the demand schedule without sectors to the forecast schedule with sectors, a conclusion of the effect of forecasts alone cannot be reached from the field data. Therefore a simulation study was initiated to compare the schedules on an equal basis. Both schedules included five sectors with irrigation decisions made daily. The schedules attempt to maintain all sectors above the same minimum moisture level. The driest sectors are always irrigated first. The only difference in the two schedules is the use of 5-day agricultural forecasts by the forecast model. This comparison removes all the variability encountered in the field tests which was not due to the presence or absence of the forecasts.

The simulation study was performed using data which corresponded as nearly as possible to the conditions encountered in the field tests each year. The weather data for Auburn, Alabama and the forecast data for southeast Alabama and northwest Florida for the years 1971, 1972, and 1973 were used. Soil parameters and planting dates used were the same as in the field tests. All 3 years' weather and forecast data were used as inputs into each model. Computer programs were run for each model to obtain available soil moisture, soil moisture excesses above total available moisture, and soil moisture deficits below the critical level for each sector and each growing day as well as to decide each irrigation that occurred. A summary of results for scheduling with forecasts and scheduling without forecasts is shown in Table 4.

An example plot of available soil-moisture versus growing day for scheduling with forecasts and scheduling without forecasts is shown in Figure 3. These results show days where the forecast schedule accomplishes the goal of moisture conservation. For example, on day 53 the scheduling with forecasts model has a smaller excess than does the scheduling without forecasts model. The forecast model successfully predicted rainfall and thus postponed an irrigation. The result was the elimination of an unneeded irrigation. Day 119 is an example where rainfall was predicted thus postponing an irrigation, but no rain occurred and a moisture deficit resulted.

TABLE 4. RESULTS OF THE SIMULATION STUDY

Results	1971		1972		1973		Average	
	With forecasts	Without forecasts	With forecasts	Without forecasts	With forecasts	Without forecasts	With forecasts	Without forecasts
Excesses (inches)[1]	8.86	9.19	10.19	10.21	4.61	4.90	7.89	8.10
Deficits for growing season (inch-days)[1]	.290	.056	.500	.060	.662	.378	.484	.165
Deficits for flowering period (inch-days)[1]	.170	.002	.476	.040	.214	.002	.287	.015
Amount of irrigation applied (inches)[1]	5.10	5.39	9.60	9.62	6.45	6.74	7.05	7.25
Day of first irrigation (growing day)	64	61	38	38	82	73	61	57
Number of irrigations[2]	24	29	38	41	38	40	33	37
Average amount of each irrigation (inches)[1]	1.06	0.93	1.26	1.17	0.85	0.84	1.05	0.98

[1] Average of all five sectors.

[2] Total of all five sectors.

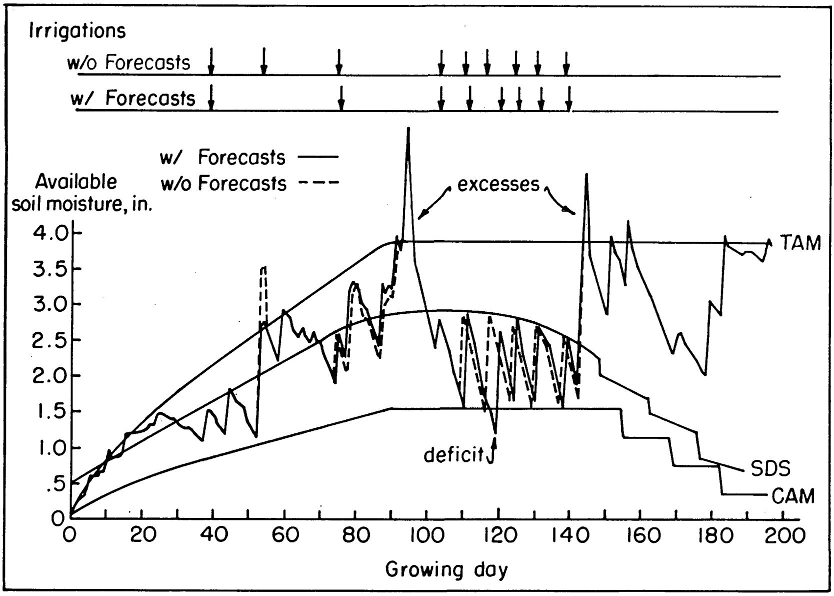

FIG. 3. Available soil moisture for scheduling with forecasts and scheduling without forecasts, (sector 1, 1973).

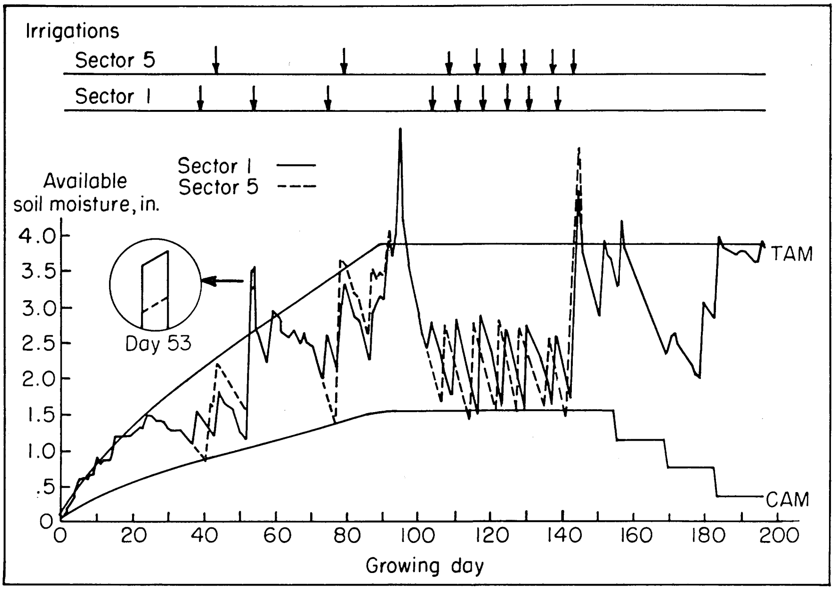

FIG. 4. Available soil moisture for sectors 1 and 5, (scheduling with forecasts).

Figure 4 shows the difference in irrigations for sectors one and five. In this case, sector five was always irrigated at least 5 days later than was sector one because of the time required to irrigate the other sectors. On day 53, an irrigation was eliminated in sector five because of rain occurring during this 5-day delay. The excess in sector five was less because of the drier soil condition. However, on day 144 rain occurred after the irrigation was made, resulting in a large excess. On days 115 and 141, a slight deficit occurred because of the delay while irrigating sectors one through four.

An analysis was made to determine the effect of scheduling with forecasts as compared to scheduling without forecasts. The analysis was made on moisture excesses and deficits and amount of irrigation applied for the complete growing season and on deficits for the flowering period. Since excesses represent inefficient use of water, the more efficient model is the one with the smaller excess. The scheduling with forecasts model produced the smaller average excess for the 3 years, but this excess was not significantly smaller than that for the scheduling without forecasts (at the 5 percent level of significance).

Since moisture deficits potentially reduce yield, a comparison of deficits was made. Scheduling with forecasts produced a higher average moisture deficit than did scheduling without forecasts (significantly different at the 5 percent level). This indicates a higher potential for yield reduction from the scheduling with forecasts model than from the scheduling without forecast model.

The amount of supplemental water applied in scheduling with forecasts was less than the amount applied in scheduling without forecasts but the reduction in amount of irrigation was small and not significant (at the 5 percent level of significance). Thus a significant saving in total amount of irrigation water was not realized in scheduling with forecasts. Results in Table 4, however, do show that scheduling with forecasts resulted in fewer number of irrigations than scheduling without forecasts. This decrease in number of irrigations is probably related to the increased deficits.

CRUSTING STUDY

The crusting study evaluated the effect that high and low application rates can have on the soil surface. Crusts can create conditions unfavorable for plant emergence. They tend to seal the surface, reducing infiltration and thus increasing the hazards of runoff and erosion.

Methods

The initial crust formation test was performed adjacent to the scheduling plots. The test area had been tilled to provide a uniform soil surface similar to a seedbed. Fifteen-inch diameter rings were driven into the ground to identify and protect the test portion of the soil surface. The ringed areas were irrigated at 0.7 and 0.13 inch per hour application rates with 1.44 inches being applied to the high application rate plots and 1.65 inches being applied to the low application rate plots. A separate set of ring plots was established outside the sprinkler area to observe the crust formed by natural rainfall. Covers were used to protect half the sprinkler ring plots from natural rainfall. All ring plots were sampled regularly with a Chatillon push-pull penetrometer having a 5/32-inch cylindrical point. The sampled area of crust was then removed for moisture determination.

Three sets of laboratory tests provided additional crust strength data where rainfall was not a variable. Observations were made on a 4-inch total water application with one and three wetting cycles and on a 1-5-inch total application with three wetting cycles. Application rates were 0.13 and 0.43 inch per hour. Where water was applied in three irrigations the soil surface was allowed to dry between applications. The soil type and sampling procedures were the same as those in the field study.

Results

Regression analyses were made to correlate penetrometer readings (crust strength) and crust moisture data. This enabled a comparison to be made over the expected moisture range and a comparison at a common moisture content. Linear, quadratic, exponential and hyperbolic equation forms were used. In both field and laboratory studies, the quadratic regression equation of penetrometer reading on crust moisture provided the best fit. These results are presented by Busch et al. *(2)*, a sample of which is shown in Figure 5.

Although the quadratic equation does provide the best fit it gives unrealistic answers when extrapolating beyond the data points. For example, negative values of crust strength are calculated at higher soil moistures. Also several of the fitted curves

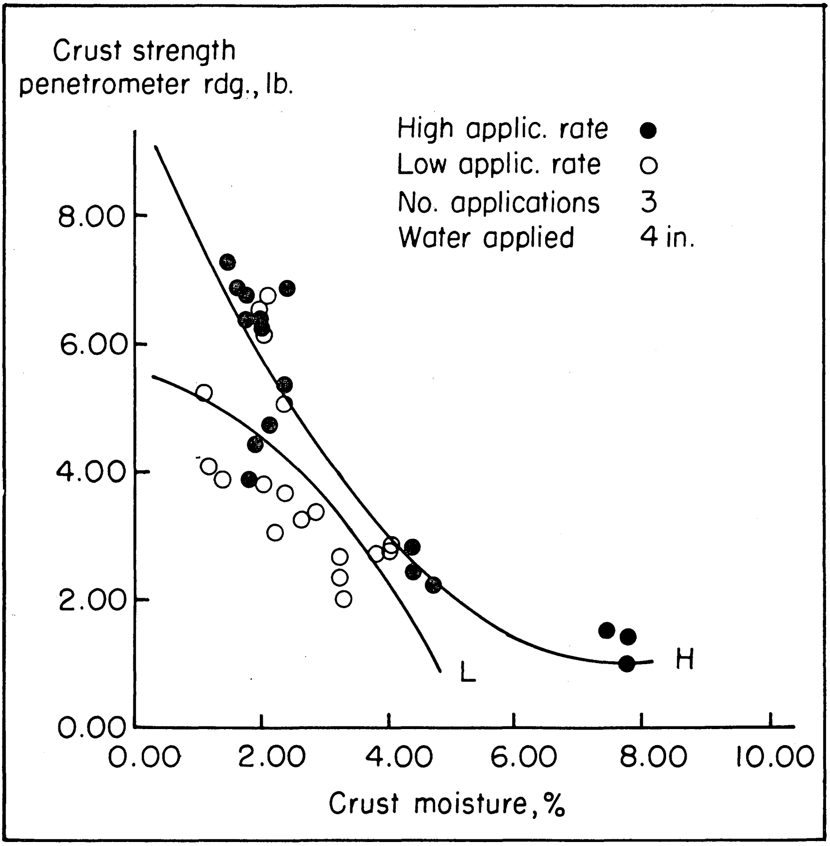

FIG. 5. Typical quadratic equation analysis.

were convex rather than the logically anticipated concave form. Therefore the data have been re-analyzed as an exponential equation to satisfy the limiting boundary conditions of a maximum crust strength value at zero crust moisture and a positive minimum value for crust strength at high moisture contents. The form of the equation is:

$$\text{Crust strength} = A\,e^{B(\text{Crust moisture})} \qquad (3)$$

where crust strength is measured in pounds and crust moisture is in percent. Values for the constants A and B were consistent over the three laboratory experiments. Averaged values are:

High application rate: $A = 11.24$ $B = -0.25$
Low application rate: $A = 8.16$ $B = -0.25$

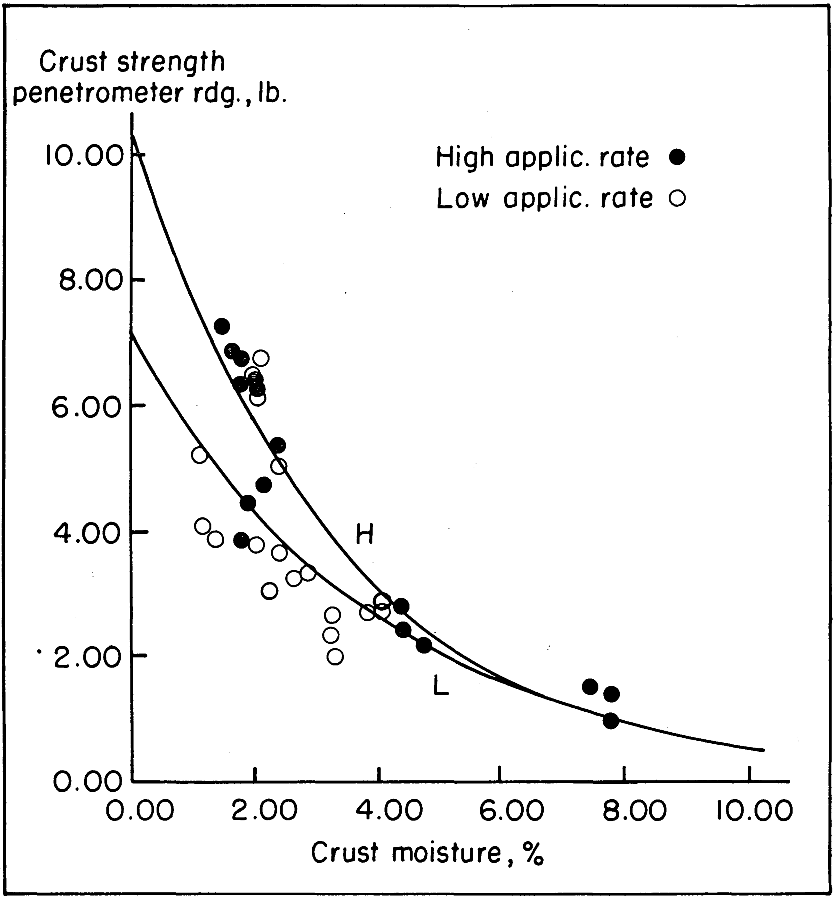

FIG. 6. Lab tests of crust strength after 3 applications, 4 inches applied.

The new analysis eliminates the possibilities of negative values and gives more realistic strength values at zero crust moisture. Moreover the average standard error of estimate differs by only 0.12 pound between the two equation forms (0.75 pound for the quadratic vs. 0.87 pound for the exponential form).

Field and laboratory results including exponential regression lines are presented in figures 6 through 10. Mean crust strengths for high and for low application rates were significantly different at the 5 percent level or less in every experiment. In a combined analysis the difference was significant at the 1 percent level.

Table 5 presents the regression equation predictions for penetrometer readings at 2 percent crust moisture. The relative posi-

TABLE 5. CRUST STRENGTH AT 2 PERCENT CRUST MOISTURE AS AFFECTED BY WATER AMOUNT AND INTENSITY

Total water applied	Water applications	Crust strength: High application rate 0.43 in. per hr.	Crust strength: Low application rate 0.13 in. per hr.
In.	*No.*	*Lb.*	*Lb.*
1.5	1	2.2*	1.5
	3	7.1	4.9
4	1	7.8	5.6
	3	5.7	4.3

* The field test high application rate was 0.7 inch per hour.

tion of the two application rates is consistent in that higher application rates produced stronger crusts. Experimental factors affecting crust strength variation that were not evaluated include differing antecedent conditions between laboratory and field tests and variation in the thickness of the crust sample at the time of sampling.

Natural rainfall produced a crust of greater strength than sprinkling or sprinkling and rainfall combined, Table 6. Unfortunately no intensity measurements were made during the storm and only the rainfall total of 2.61 inches was recorded. However, these preliminary results suggest that previous sprinkling can reduce the strength of crust formed by a subsequent rainfall.

Schleusener and Kidder *(13)* pointed out that the true application rates based on the actual time water falls at a point location are 50 to 90 times the apparent sprinkler application rate. In this perspective the magnitude of sprinkler intensities is much larger than the figures normally reported, and considerably different from intensities used in simulated rainfall studies which maintain a relatively low constant application rate. Further research is

TABLE 6. RAINFALL EFFECT ON CRUST STRENGTH AT 2 PERCENT CRUST MOISTURE

Type of application	Water applied	Crust strength: High application rate 0.7 in. per hr.	Crust strength: Low application rate 0.13 in. per hr.	Crust strength: Rainfall plot
	In.	*Lb.*	*Lb.*	*Lb.*
Irrigation only	1.5	2.2	1.5	
Irrigation + rainfall	4.11	3.3	2.8	
Rainfall	2.61			5.3

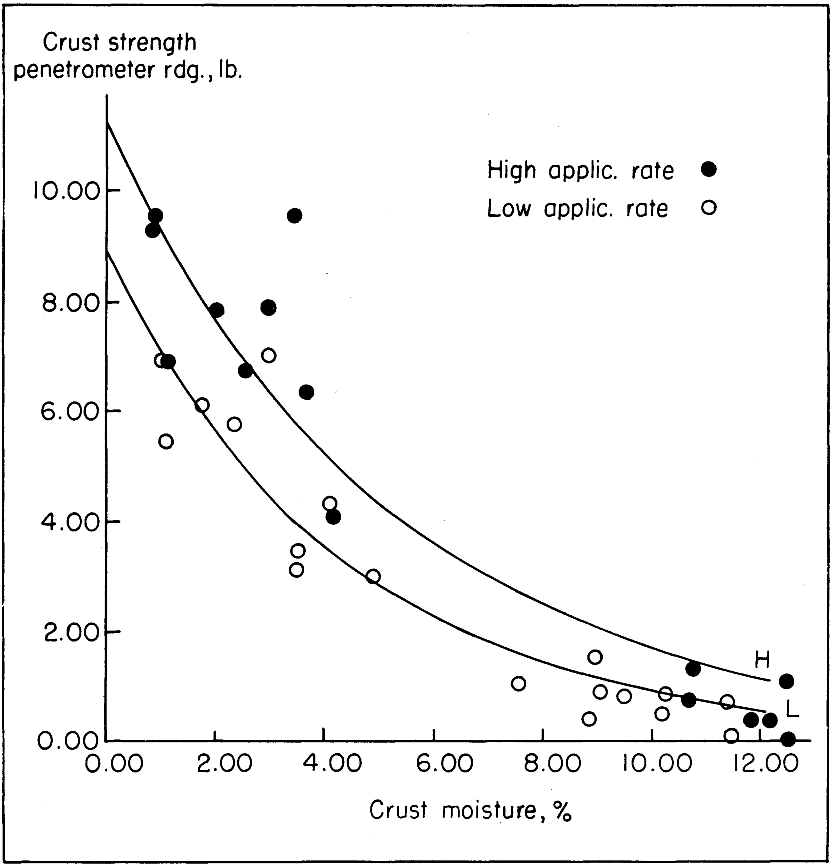

FIG. 7. Lab test of crust strength after one application, 4 inches applied.

needed on the effect of actual instantaneous sprinkler application rates on soil structure.

In these experiments crust strengths developed under two different sprinkling intensities persist over three wetting and drying cycles. Lower sprinkler application rates consistently produced a weaker crust. Increasing the number of water application cycles did not show a consistent effect on crust strength. And finally, previous sprinkling may reduce the strength of a crust formed by a subsequent rainfall.

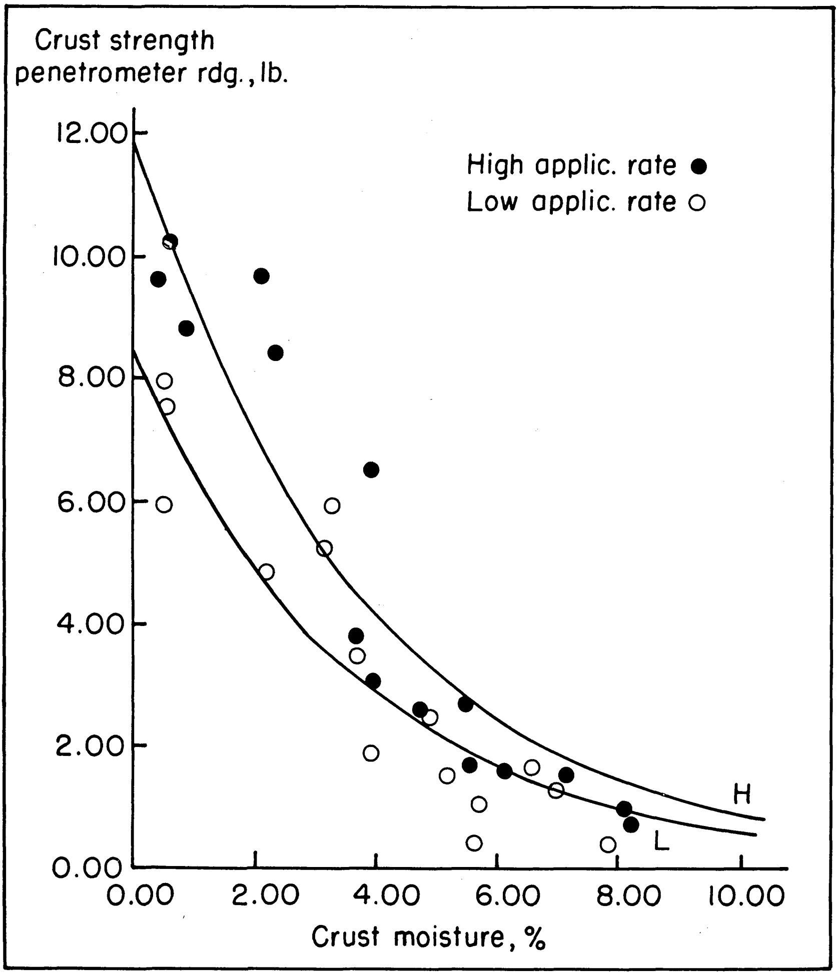

FIG. 8. Lab test of crust strength after three applications, 1.5 inches applied.

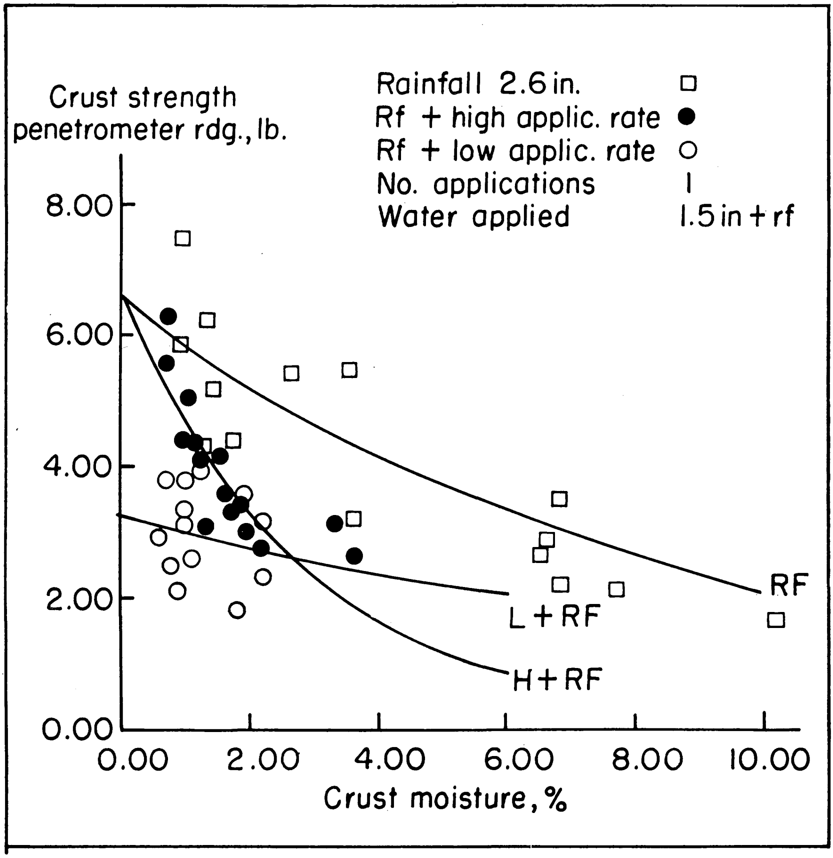

FIG. 9. Field test of crust strengths combining rainfall with irrigation.

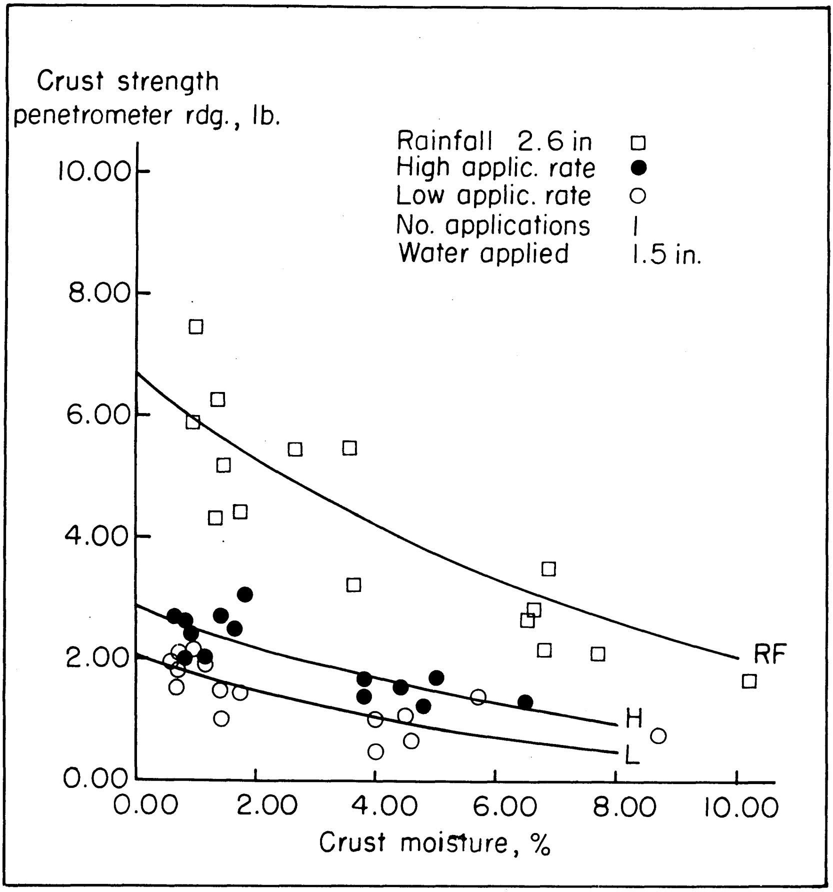

FIG. 10. Field test of crust strengths, irrigation and rainfall separated.

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* Principle publications presenting interim results from the study described in this Bulletin.

APPENDIX

Appendix Table 1. Definitions of Parameters Used In The FORTRAN Programs

A	NUMBER OF DAYS IN 79 PERCENT OF GROWING SEASON
AMPF	AVAILABLE MOISTURE PER FOOT EXPRESSED IN INCHES OF WATER PER FOOT OF SOIL
ASET	ASSUMED EVAPOTRANSPIRATION EXPRESSED IN INCHES PER DAY
AVM	AVAILABLE MOISTURE TO THE PLANT EXPRESSED IN INCHES OF WATER
AWA	OBSOLETE VARIABLE NAME
B	NUMBER OF DAYS IN 86 PERCENT OF GROWING SEASON
CAM	CRITICAL AVAILABLE MOISTURE EXPRESSED IN INCHES OF WATER
CC	NUMBER OF DAYS IN 93 PERCENT OF GROWING SEASON
CP	CONDITIONAL PROBABILITIES AS REPORTED BY ALLEN
DSM	DAILY SOIL MOISTURE ADDED DUE TO ROOT DEPTH INCREASE-EXPRESSED IN INCHES OF WATER
ET	EVAPOTRANSPIRATION EXPRESSED IN INCHES OF WATER PER DAY
EXC	EXCESS SOIL MOISTURE EXPRESSED IN INCHES OF WATER
FACTOR	PERCENT OF GROWING SEASON FOR DAY I
FROST	MOST LIKELY DATE OF THE FIRST FROST EXPRESSED IN JULIAN DAYS
FXPR	FORECAST RAINFALL AMOUNT TOTAL FOR TODAY, TONIGHT, AND TOMORROW EXPRESSED IN INCHES OF WATER
I	DUMMY VARIABLE USED TO INCREMENT TIME EXPRESSED IN DAYS
ID	DUMMY VARIABLE USED TO IDENTIFY TIME IN THE LIST OF DATA STORED ON MAGNETIC TAPE-EXPRESSED IN DAYS FROM PLANTING
IM	DUMMY VARIABLE USED TO INCREMENT FUTURE TIME EXPRESSED IN DAYS
IN	MATRIX USED TO IDENTIFY SECTOR IRRIGATION NEEDS WITH 1 REPRESENTING AN IRRIGATION NEED AND 0 REPRESENTING NO NEED
INT	SCALER VALUE OF IN INDICATING THE NEED OF IRRIGATION FOR DAY AND SECTOR UNDER CONSIDERATION
INTFAC	PERCENT OF GROWING SEASON FOR DAY I EXPRESSED AS AN INTEGER
J	DUMMY VARIABLE USED TO INCREMENT SECTORS
JJ	NUMBER OF WHOLE DAYS IN FIRST 79 PERCENT OF GROWING SEASON
K	NUMBER OF THE DAY AFTER 79 PERCENT OF GROWING SEASON HAS BEEN COMPLETED-EXPRESSED IN DAYS AFTER PLANTING
KK	NUMBER OF THE DAY AFTER 93 PERCENT OF GROWING SEASON HAS BEEN COMPLETED-EXPRESSED IN DAYS AFTER PLANTING
L	NUMBER OF THE DAY AFTER 86 PERCENT OF GROWING SEASON HAS BEEN COMPLETED-EXPRESSED IN DAYS AFTER PLANTING
LENGTH	LENGTH OF THE GROWING SEASON EXPRESSED IN DAYS
LFD	FIRST DAY OF UPDATE CALCULATIONS EXPRESSED IN DAYS FROM PLANTING

Appendix Table 1. Continued

LLD	LAST DAY OF UPDATE CALCULATIONS EXPRESSED IN DAYS FROM PLANTING
LYD	ONE DAY PRIOR TO UPDATE CALCULATIONS EXPRESSED IN DAYS FROM PLANTING
MAMFIR	MAXIMUM AVAILABLE MOISTURE FOR IRRIGATION RECHARGE-EXPRESSED IN INCHES OF WATER
MM	NUMBER OF WHOLE DAYS IN 86 PERCENT OF GROWING SEASON
MMM	NUMBER OF 7TH DAY PRIOR TO END OF GROWING SEASON-EXPRESSED IN DAYS FROM PLANTING
MMMM	NUMBER OF 6TH DAY PRIOR TO END OF GROWING SEASON-EXPRESSED IN DAYS FROM PLANTING
N	NUMBER OF JULIAN DAYS PRIOR TO PLANTING DATE
NNN	NUMBER OF DAYS IN 93 PERCENT OF GROWING SEASON EXPRESSED AS AN INTEGER
PE	PAN EVAPORATION EXPRESSED IN INCHES PER DAY
PK	CROP COEFFICIENTS INCREMENTED IN PERCENT OF GROWING SEASON
PKD	CROP COEFFICIENTS INCREMENTED IN GROWING DAYS
PLANT	PLANTING DATE EXPRESSED IN JULIAN DAYS
PR	PRECIPITATION EXPRESSED IN INCHES
PROB	DAILY RAINFALL PROBABILITIES FOR THE PERIODS TODAY, TONIGHT, AND TOMORROW
PROB1	RAINFALL PROBABILITY FOR TODAY
PROB2	RAINFALL PROBABILITY FOR TONIGHT
PROB3	RAINFALL PROBABILITY FOR TOMORROW
PROB13	COMBINED RAINFALL PROBABILITY FOR THE PERIOD TODAY, TONIGHT, AND TOMORROW
ROOT	ROOTING DEPTHS INCREMENTED IN GROWING DAYS AND EXPRESSED IN FEET
SDS	AVAILABLE MOISTURE REQUIRED TO HAVE A SEVEN DAY SUPPLY ABOVE CAM EXPRESSED IN INCHES AND EVALUATED AT DAY'S END
SI	MOISTURE ADDED BY SPRINKLER IRRIGATION EXPRESSED IN INCHES
TAM	TOTAL MOISTURE AVAILABLE TO PLANT IN THE RANGE FROM 0.33 BARS TO 15 BARS EXPRESSED IN INCHES
XAM	EXPECTED AVAILABLE MOISTURE FOR FUTURE DAYS EXPRESSED IN INCHES
XPR	EXPECTED PRECIPITATION FOR FUTURE DAYS EXPRESSED IN INCHES
XPR1	EXPECTED PRECIPITATION FOR TODAY EXPRESSED IN INCHES
XPR2	EXPECTED PRECIPITATION FOR TODAY, TONIGHT, AND TOMORROW EXPRESSED IN INCHES

Appendix Table 2. FORTRAN Program to Calculate and Store Initial Data on Magnetic Tape

```
      INTEGER PLANT, FROST
      REAL MAMFIR
      DIMENSION ROOT(225),PE(364),ASET(225),TAM(225),DSM(225),ID(225),
     1MAMFIR(225),SDS(225),CAM(225),PK(100),PKD(225)
      READ(5,1)AMPF
  1   FORMAT(F10.2)
      READ(5,5)PLANT, FROST
  5   FORMAT(2I10)
      LENGTH = FROST - PLANT
      READ(5,10)ROOT
  10  FORMAT(5F10.2)
      READ(5,12)PE
 12   FORMAT(13F5.3)
      READ(5,15)PK
 15   FORMAT(13F5.3)
      PKD(1) = PK(1)
      DO 20 I=2,LENGTH
      FACTOR = I*100.0/LENGTH
      INTFAC = IFIX(FACTOR)
      PKD(I) = PK(INTFAC)
 20   CONTINUE
      N = PLANT - 1
      DO 25 I=1,LENGTH
      ASET(I) = PE(I+N)*PKD(I)
 25   CONTINUE
      TAM(1) = ROOT(1)*AMPF
      DSM(1) = ROOT(1)*AMPF
      ID(1) = 1
      DO 30 I=2,LENGTH
      ID(I) = I
      DSM(I) = (ROOT(I)-ROOT(I-1))*AMPF
      TAM(I) = TAM(I-1) + DSM(I)
 30   CONTINUE
      A = 0.79*LENGTH
      JJ = IFIX(A)
C 1 TO A IS FIRST SEGMENT OF GROWING SEASON (79 PERCENT)

      DO 40 I=1,JJ
      CAM(I) = 0.4*TAM(I)
      MAMFIR(I) = TAM(I)
 40   CONTINUE
      K = JJ+1
      B = 0.86*LENGTH
C K TO B IS SECOND SEGMENT OF GROWING SEASON ( 7 PERCENT)
      MM = IFIX(B)
      DO 50 I=K,MM
      CAM(I) = 0.3*TAM(I)
      MAMFIR(I) = 0.9*TAM(I)
 50   CONTINUE
      L = MM+1
      CC = 0.93*LENGTH

C L TO CC IS THIRD SEGMENT OF GROWING SEASON (7 PERCENT)

      NNN = IFIX(CC)
      DO 60 I=L,NNN
      CAM(I) = 0.2*TAM(I)
      MAMFIR(I) = 0.8*TAM(I)
 60   CONTINUE
      KK = NNN+1

C KK TO LENGTH IS FINAL SEGMENT OF GROWING SEASON (7 PERCENT)

      DO 70 I=KK,LENGTH
      CAM(I) = 0.1*TAM(I)
      MAMFIR(I) = 0.7*TAM(I)
 70   CONTINUE
      MMM = LENGTH - 7
      DO 80 I=1,MMM
      SDS(I)=CAM(I+7)+ASET(I+1)+ASET(I+2)+ASET(I+3)+ASET(I+4)+ASET(I+5)
```

Appendix Table 2. Continued

```
     1+ASET(I+6)+ASET(I+7)
80     CONTINUE
       MMMM = MMM+1
       DO 90 I=MMMM,LENGTH
       SDS(I) = 0.
90     CONTINUE
       WRITE(6,100)(ID(I),ROOT(I),PE(I+N),PKD(I),ASET(I),TAM(I),CAM(I),
     1MAMFIR(I),DSM(I),SDS(I),I=1,LENGTH)
100    FORMAT(I8,9F7.3)
       WRITE(1,105)LENGTH
105    FORMAT(I3)
       WRITE(1,110)(ID(I),ROOT(I),PKD(I),TAM(I),MAMFIR(I),CAM(I),
     1ASET(I),DSM(I),SDS(I),I=1,LENGTH)
110    FORMAT(I8,8F9.3)
       STOP
       END
```

Appendix Table 3. FORTRAN Program to Calculate and Report Irrigation Needs

```
      REAL MAMFIR
      DIMENSION ROOT(225),PKD(225),ET(225),AVM(225,5),DSM(225),
     1ASET(225),SI(225,5),PR(225),TAM(225),CAM(225),EXC(225,5),XAM(225,
     25,5),XPR(225,5),ID(225),IN(225,5,5),AWA(5,5),PROB(225,3),CP(2,10),
     3FXPR(225),PROB13(225),MAMFIR(225),SDS(225),PE(225)
      READ(1,5)LENGTH
  5   FORMAT(I3)
      READ(1,10)(ID(I),ROOT(I),PKD(I),TAM(I),MAMFIR(I),CAM(I),
     1ASET(I),DSM(I),SDS(I),I=1,LENGTH)
  10  FORMAT(I8,8F9.3)

C     READ(1,   IS A STATEMENT TO READ SOIL, CROP & WEATHER DATA
C     WHICH HAS BEEN PREVIOUSLY STORED ON MAGNETIC TAPE

      REWIND 01
  110 READ(5,111)LFD,LLD
  111 FORMAT(2I10)
      WRITE(6,111)LFD,LLD
      LYD=LFD-1
      IF(LFD-1)300,114,112
  112 READ(3,113)(PE(I),ET(I),PR(I),FXPR(I),
     1PROB(I,1),PROB(I,2),PROB(I,3),
     2SI(I,1),SI(I,2),SI(I,3),SI(I,4),SI(I,5),
     3AVM(I,1),AVM(I,2),AVM(I,3),AVM(I,4),AVM(I,5),
     4EXC(I,1),EXC(I,2),EXC(I,3),EXC(I,4),EXC(I,5),
     5XPR(I,1),XPR(I,2),XPR(I,3),XPR(I,4),XPR(I,5),
     6XAM(I,1,1),XAM(I,1,2),XAM(I,1,3),XAM(I,1,4),XAM(I,1,5),
     6XAM(I,2,1),XAM(I,2,2),XAM(I,2,3),XAM(I,2,4),XAM(I,2,5),
     6XAM(I,3,1),XAM(I,3,2),XAM(I,3,3),XAM(I,3,4),XAM(I,3,5),
     6XAM(I,4,1),XAM(I,4,2),XAM(I,4,3),XAM(I,4,4),XAM(I,4,5),
     6XAM(I,5,1),XAM(I,5,2),XAM(I,5,3),XAM(I,5,4),XAM(I,5,5),
     7I=1,LYD)
  113 FORMAT(13F6.3)

C     READ( 3     IS A STATEMENT TO READ FROM MAGNETIC TAPE
C     THE DATA FOR THE GROWING SEASON UNDER CONSIDERATION

  114 READ(5,115)(PE(I),(SI(I,J),J=1,5),PR(I),(PROB(I,J),J=1,3),FXPR(I),
     1(XPR(I,IM),IM=3,5),I=LFD,LLD)
  115 FORMAT(7F10.3,/7F10.3)

C     SPRINKLER IRRIGATION AND PRECIPATION.  CARD 2 CONTAINS PROBILITIES
C     FOR TODAY, TONIGHT, AND TOMORROW, FORECASTED PRECIPATION FOR THE
C     PERIOD, AND EXPECTED PRECIPATION FOR DAYS THREE FOUR AND FIVE..
C     IN ADDITION EACH CARD HAS THE DATE/CARD NUMBER/YEAR IN POSITIONS
C.    71-80.  EXAMPLE 01/125/71.  SEE CARD 115 FOR FORMAT
```

Appendix Table 3. Continued

```
      WRITE(6,116)
  116 FORMAT(1H1,16X,'DATE',36X,'IRRIG     SCH     BY     SECTORS'/38X,'1',
     220X,'2',20X,'3',20X,'4',20X,'5')
      I=0
      IF(LFD.GE.6) I=LFD-6
  117 I=I+1
      WRITE(6,118)I,(SI(I,J),J=1,5)
  118 FORMAT(1X,I20,5F20.2)
      IF(I-LLD)117,119,300
  119 IF(LFD-1)300,120,130

C     CALCULATIONS OF EVAPOTRANSPIRATION, AVAILABLE MOISTURE,
C     EXCESS MOISTURE, AND EXPECTED AVAILABLE MOISTURE

  120 I=1
      XPR(I,1)=0
      XPR(I,2)=0
      CALL PREC(PROB(I,1),PROB(I,2),PROB(I,3),FXPR(I),PROB13(I),XPR(I,1
     1),XPR(I,2))
      ET(1)=PE(1)*PKD(1)
      J=0
  121 J=J+1
      AVM(1,J)=DSM(1)-ET(1)
      EXC(1,J)=0
      IM=1
      XAM(1,J,1 )=AVM(1,J)+DSM(2)-ASET(2)+XPR(1,1)
      IF(XAM(1,J,1 )-TAM(2))123,123,122
  122 XAM(1,J,IM)=TAM(2)
  123 IM=IM+1
      XAM(1,J,IM)=XAM(1,J,IM-1)+DSM(1+IM)-ASET(1+IM)+XPR(1,IM)
      IF(XAM(1,J,IM)-TAM(1+IM))125,125,124
  124 XAM(1,J,IM)=TAM(1+IM)
  125 IF(IM-5)123,128,128
  128 IF(J-5)121,129,300
  129 IF(I-LLD)148,185,300
  130 I=LFD-1
  148 I=I+1
      J=0
      ET(I)=PE(I)*PKD(I)
      XPR(I,1)=0
      XPR(I,2)=0
      CALL PREC(PROB(I,1),PROB(I,2),PROB(I,3),FXPR(I),PROB13(I),XPR(I,1
     1),XPR(I,2))
  150 J=J+1
      EXC(I,J)=0
      AVM(I,J)=AVM(I-1,J)+PR(I)+DSM(I)-ET(I)+SI(I,J)
      IF(AVM(I,J)-TAM(I))161,161,160
  160 EXC(I,J)=AVM(I,J)-TAM(I)
      AVM(I,J)=TAM(I)
  161 IM=1
      XAM(I,J,IM)=AVM(I,J)+DSM(I+1)-ASET(I+1)+XPR(I,IM)
      IF(XAM(I,J,IM)-TAM(I+IM))163,163,162
  162 XAM(I,J,IM)=TAM(I+IM)
  163 IF(I-LLD)165,600,300
  165 IM=IM+1
      XAM(I,J,IM)=XAM(I,J,IM-1)+DSM(I+IM)-ASET(I+IM)+XPR(I,IM)
      IF(XAM(I,J,IM)-TAM(I+IM))168,168,167
  167 XAM(I,J,IM)=TAM(I+IM)
  168 IF(I-LLD)169,650,300
  169 IF(IM-5)165,170,170
  170 IF(J-5)150,180,180
  180 IF(I-LLD)148,185,185

C     WRITE( 3     IS A STATEMENT TO WRITE ON MAGNETIC TAPE THE
C     DATA FOR THE GROWING SEASON UNDER CONSIDERATION

  185 WRITE(3,113)(PE(I),ET(I),PR(I),FXPR(I),
     1PROB(I,1),PROB(I,2),PROB(I,3),
     2SI(I,1),SI(I,2),SI(I,3),SI(I,4),SI(I,5),
     3AVM(I,1),AVM(I,2),AVM(I,3),AVM(I,4),AVM(I,5),
     4EXC(I,1),EXC(I,2),EXC(I,3),EXC(I,4),EXC(I,5),
     5XPR(I,1),XPR(I,2),XPR(I,3),XPR(I,4),XPR(I,5),
     6XAM(I,1,1),XAM(I,1,2),XAM(I,1,3),XAM(I,1,4),XAM(I,1,5),
```

Appendix Table 3. Continued

```
     6XAM(I,2,1),XAM(I,2,2),XAM(I,2,3),XAM(I,2,4),XAM(I,2,5),
     6XAM(I,3,1),XAM(I,3,2),XAM(I,3,3),XAM(I,3,4),XAM(I,3,5),
     6XAM(I,4,1),XAM(I,4,2),XAM(I,4,3),XAM(I,4,4),XAM(I,4,5),
     6XAM(I,5,1),XAM(I,5,2),XAM(I,5,3),XAM(I,5,4),XAM(I,5,5),
     7I=LFD,LLD)

C     STATEMENTS TO WRITE ON PAPER THE RECORDED PRECIPATION,
C     EXPECTED PRECIPATION, PAN EVAPORATION, AND EVAPOTRANSPIRATION
C     FOR UPDATE DATES


  190 WRITF(6,200)
  200 FORMAT(///,5X,'DATE',7X,'PR',27X,'XPR',28X,'PE',8X,'ET',/
     128X,'1',9X,'2',9X,'3',9X,'4',9X,'5')
      I=LFD-1
  201 I=I+1
      IF(I-1)300,202,217
C     IF LFD NOT 1, IT MUST BE AT LEAST 7
  202 WRITE(6,203) I,PR(I),PE(I),ET(I)
  203 FORMAT(1X,I10,F10.2,50X,2F10.2)
      IF(I-LLD)205,223,223
  205 I=I+1
      WRITE(6,206) I,PR(I),XPR(I-1,1),PE(I),ET(I)
  206 FORMAT(1X,I10,2F10.2,40X,2F10.2)
      IF(I-LLD)207,223,223
  207 I=I+1
  208 WRITE(6,209) I,PR(I),XPR(I-1,1),XPR(I-2,2),PE(I),ET(I)
  209 FORMAT(1X,I10,3F10.2,30X,2F10.2)
      IF(I-LLD)210,223,223
  210 I=I+1
  211 WRITE(6,212) I,PR(I),XPR(I-1,1),XPR(I-2,2),XPR(I-3,3),
     1PE(I),ET(I)
  212 FORMAT(1X,I10,4F10.2,20X,2F10.2)
      IF(I-LLD)213,223,223
  213 I=I+1
  214 WRITE(6,215) I,PR(I),XPR(I-1,1),XPR(I-2,2),XPR(I-3,3),
     1XPR(I-4,4),PE(I),ET(I)
  215 FORMAT(1X,I10,5F10.2,10X,2F10.2)
      IF(I-LLD)216,223,223
  216 I=I+1
  217 WRITE(6,218)I,PR(I),XPR(I-1,1),XPR(I-2,2),XPR(I-3,3),
     1XPR(I-4,4),XPR(I-5,5),PE(I),ET(I)
  218 FORMAT(1X,I10,8F10.2)
      IF(I-LLD)216,226,300

C     NOTIFICATION OF UNACCEPTABLE VALUE OF LLD

  223 WRITE(6,224)
  224 FORMAT(1X,'LLD MUST BE AT LEAST 6')
      GO TO 300

C     STATEMENTS TO WRITE ON PAPER THE EXPECTED PRECIPATION
C     FOR FUTURE DATES

  226 I=I+1
      WRITE(6,228)I,XPR(I-1,1),XPR(I-2,2),XPR(I-3,3),XPR(I-4,4),
     1XPR(I-5,5)
  228 FORMAT(1X,I10,10X,5F10.2)
      I=I+1
      WRITE(6,231)I,XPR(I-2,2),XPR(I-3,3),XPR(I-4,4),XPR(I-5,5)
  231 FORMAT(1X,I10,20X,4F10.2)
      I=I+1
      WRITE(6,234)I,XPR(I-3,3),XPR(I-4,4),XPR(I-5,5)
  234 FORMAT(1X,I10,30X,3F10.2)
      I=I+1
      WRITE(6,237)I,XPR(I-4,4),XPR(I-5,5)
  237 FORMAT(1X,I10,40X,2F10.2)
      I=I+1
      WRITE(6,238)I,XPR(I-5,5)
  238 FORMAT(1X,I10,50X,F10.2)

C     STATEMENTS TO WRITE ON PAPER THE AVAILABLE MOISTURE, EXCESS
```

Appendix Table 3. Continued

```
C       MOISTURE, AND EXPECTED AVAILABLE MOISTURE FOR UPDATE DATES

        J=0
  239   J=J+1
        WRITE(6,260)J
  260   FORMAT(///,36X,'SECTOR',I2,//3X,'DATE',3X,'AVAILABLE',3X,'EXCESS',
       114X,'AVAILABLE MOISTURE  PREDICTIONS',8X,'CAM',5X,'TAM',3X,
       2'MAMFIR',3X,'SDS'/
       311X,'MOISTURE',2X,'MOISTURE',19X,'DAYS IN ADVANCE'/
       3/34X,'1',9X,'2',9X,'3',9X,'4',9X,'5')
        I=LFD
        IF(LFD-6)263,277,277
  263   IF(I-1)300,264,223
  264   WRITE(6,265)I,AVM(I,J),EXC(I,J)
  265   FORMAT(1X,I5,2F10.2)
        I=I+1
        WRITE(6,267) I,AVM(I,J),EXC(I,J),XAM(I-1,J,1)
  267   FORMAT(1X,I5,3F10.2)
        I=I+1
        WRITE(6,270)I,AVM(I,J),EXC(I,J),XAM(I-1,J,1),XAM(I-2,J,2)
  270   FORMAT(1X,I5,4F10.2)
        I=I+1
        WRITE(6,273)I,AVM(I,J),EXC(I,J),XAM(I-1,J,1),XAM(I-2,J,2),
       1XAM(I-3,J,3)
  273   FORMAT(1X,I5,5F10.2)
        I=I+1
        WRITE(6,275)I,AVM(I,J),EXC(I,J),XAM(I-1,J,1),XAM(I-2,J,2),
       1XAM(I-3,J,3),XAM(I-4,J,4)
  275   FORMAT(1X,I5,6F10.2)
  276   I=I+1
  277   WRITE(6,279)I,AVM(I,J),EXC(I,J),XAM(I-1,J,1),XAM(I-2,J,2),
       1XAM(I-3,J,3),XAM(I-4,J,4),XAM(I-5,J,5),CAM(I),TAM(I)
  279   FORMAT(1X,I5,7F10.2,2F8.2)
        IF(I-LLD)276,280,223
  280   I=I+1

C PRINTOUT OF XAM FOR DATES GREATER THAN LAST I.E. GREATER THAN LLD

        INT=0
        INT=IN(I-1,J,1)
        IF(INT-1)283,383,283
  283   WRITE(6,284)I,XAM(I-1,J,1),XAM(I-2,J,2),XAM(I-3,J,3),
       1XAM(I-4,J,4),XAM(I-5,J,5),
       1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  284   FORMAT(1X,I5,20X,5F10.2,4F8.2)
  286   I=I+1
        INT=0
        INT=2*IN(I-2,J,1)+IN(I-2,J,2)
        IF(INT-1)287,387,287
  287   WRITE(6,288)I,XAM(I-2,J,2),XAM(I-3,J,3),XAM(I-4,J,4),
       1XAM(I-5,J,5),
       1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  288   FORMAT(1X,I5,30X,4F10.2,4F8.2)
  289   I=I+1
        INT=0
        INT=2*IN(I-3,J,1)+2*IN(I-3,J,2)+IN(I-3,J,3)
        IF(INT-1)290,390,290
  290   WRITE(6,291)I,XAM(I-3,J,3),XAM(I-4,J,4),XAM(I-5,J,5),
       1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  291   FORMAT(1X,I5,40X,3F10.2,4F8.2)
  292   I=I+1
        INT=0
        INT=2*IN(I-4,J,1)+2*IN(I-4,J,2)+2*IN(I-4,J,3)+IN(I-4,J,4)
        IF(INT-1)293,393,293
  293   WRITE(6,294)I,XAM(I-4,J,4),XAM(I-5,1,5),
       1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  294   FORMAT(1X,I5,50X,2F10.2,4F8.2)
  295   I=I+1
        INT=0
        INT=2*IN(I-5,J,1)+2*IN(I-5,J,2)+2*IN(I-5,J,3)+2*IN(I-5,J,4)+
       1IN(I-5,J,5)
        IF(INT-1)296,396,296
```

Appendix Table 3. Continued

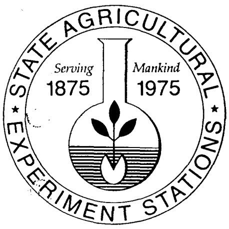
```
  296 WRITE(6,297)I,XAM(I-5,J,5),
     1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  297 FORMAT(1X,I5,60X,1F10.2,4F8.2)
  298 IF(J-5)239,300,300
  600 CONTINUE
      IF(XAM(I,J,IM)-CAM(I+IM))620,620,630
  620 IN(I,J,IM)=1
      GO TO 165
  630 IN(I,J,IM)=0
      GO TO 165
  650 CONTINUE
      IF(XAM(I,J,IM)-CAM(I+IM))660,660,670
  660 IN(I,J,IM)=1
      GO TO 169
  670 IN(I,J,IM)=0
      GO TO 169

C WRITE STATEMENTS FOR DAYS REQUIRING IRRIGATION

  383 WRITE(6,384)I,XAM(I-1,J,1),XAM(I-2,J,2),XAM(I-3,J,3),XAM(I-4,J,4)
     1,XAM(I-5,J,5),
     1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  384 FORMAT(1X,I5,20X,5F10.2,4F8.2,2X,' DAY   1')
      GO TO 286
  387 WRITE(6,388)I,XAM(I-2,J,2),XAM(I-3,J,3),XAM(I-4,J,4),XAM(I-5,J,5)
     1,
     1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  388 FORMAT(1X,I5,30X,4F10.2,4F8.2,2X,' DAY   2')
      GO TO 289
  390 WRITE(6,391)I,XAM(I-3,J,3),XAM(I-4,J,4),XAM(I-5,J,5),
     1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  391 FORMAT(1X,I5,40X,3F10.2,4F8.2,2X,'DAY   3')
      GO TO 292
  393 WRITE(6,394)I,XAM(I-4,J,4),XAM(I-5,J,5),
     1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  394 FORMAT(1X,I5,50X,2F10.2,4F8.2,2X,' DAY   4')
      GO TO 295
  396 WRITE(6,397)I,XAM(I-5,J,5),
     1CAM(I),TAM(I),MAMFIR(I),SDS(I)
  397 FORMAT(1X,I5,60X,1F10.2,4F8.2,2X,'DAY   5')
      GO TO 298
  300 STOP
      END
```

Appendix Table 4. FORTRAN Subroutine to Calculate Combined Rainfall Probabilities

```
SUBROUTINE PREC (PROB1,PROB2,PROB3,FXPR,PROB13,XPR1,XPR2)
DIMENSION CP(2,10)
CP(1,1)=.15
CP(1,2)=.18
CP(1,3)=.27
CP(1,4)=.40
CP(1,5)=.53
CP(1,6)=.64
CP(1,7)=.70
CP(1,8)=.82
CP(1,9)=.90
CP(1,10)=.96
CP(2,1)=0
CP(2,2)=.11
CP(2,3)=.22
CP(2,4)=.33
CP(2,5)=.46
CP(2,6)=.59
CP(2,7)=.71
CP(2,8)=.81
CP(2,9)=.89
CP(2,10)=.95
PROB13=PROB1+PROB2+PROB3-PROB1*CP(1,(10*PROB2+1.5)-
   1PROB2*CP(2,(10*PROB3+1.5))
    IF(PROB1-0.5)21,22,22
 22 XPR1=FXPR
    GO TO 90
 21 IF(PROB13-0.5)90,24,24
 24 XPR2=FXPR
 90 RETURN
    END
```

APPENDIX TABLE 5. SAMPLE PRINT-OUT OF THE IRRIGATION SCHEDULING COMPUTER PROGRAM

Date	Available moisture	Excess moisture	Available moisture predictions days in advance					CAM	TAM	SDS
			1	2	3	4	5			
					SECTOR 3					
57	1.52	0.0	1.51	1.47	2.40	1.31	1.70	1.12	2.79	
58			1.39	1.38	1.34	2.27	1.18	1.13	2.83	2.54
59				1.49	1.23	1.19	2.12	1.14	2.86	2.57
60					1.35	1.09	1.05	1.16	2.90	2.61
61						1.20	0.94	1.17	2.94	2.63
62							1.05	1.19	2.98	2.65 DAY 5
					SECTOR 4					
57	1.52	0.0	1.51	1.47	2.40	1.31	1.70	1.12	2.79	
58			1.39	1.38	1.34	2.27	1.18	1.13	2.83	2.54
59				1.49	1.23	1.19	2.12	1.14	2.86	2.57
60					1.35	1.09	1.05	1.16	2.90	2.61
61						1.20	0.94	1.17	2.94	2.63
62							1.05	1.19	2.98	2.65 DAY 5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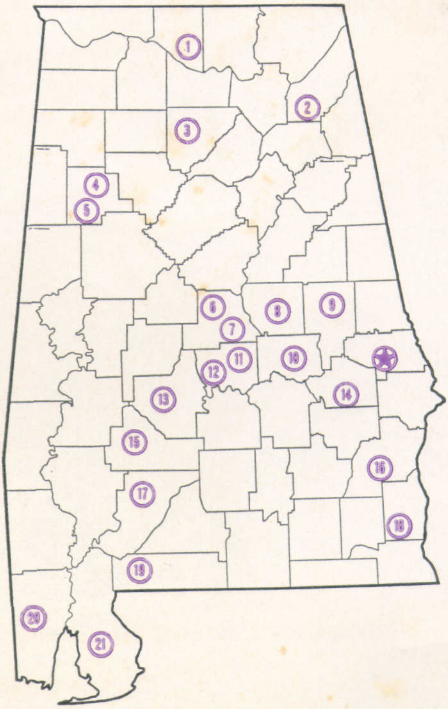

Research Unit Identification

★ Main Agricultural Experiment Station, Auburn.

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
5. Forestry Unit, Fayette County.
6. Thorsby Foundation Seed Stocks Farm, Thorsby.
7. Chilton Area Horticulture Substation, Clanton.
8. Forestry Unit, Coosa County.
9. Piedmont Substation, Camp Hill.
10. Plant Breeding Unit, Tallassee.
11. Forestry Unit, Autauga County.
12. Prattville Experiment Field, Prattville.
13. Black Belt Substation, Marion Junction.
14. Tuskegee Experiment Field, Tuskegee.
15. Lower Coastal Plain Substation, Camden.
16. Forestry Unit, Barbour County.
17. Monroeville Experiment Field, Monroeville.
18. Wiregrass Substation, Headland.
19. Brewton Experiment Field, Brewton.
20. Ornamental Horticulture Field Station, Spring Hill.
21. Gulf Coast Substation, Fairhope.