EFFECT OF WHEAT DOUBLE FALLOW
ON
WATER STORAGE AND DRAINAGE

by

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CHAPTER 1 INTRODUCTION

Wheat is one of the most important crop products in western Kansas. But, low and unfavorable distribution of precipitation, extended drought periods, and excessive evaporation have always been limiting factors of wheat production. Irrigation on this area is impractical, because the major water resource comes from underground. Due to low rainfall, and tight overburden material, (Bouwer, 1978) however, soils hold most rainfall in the rooting zone of native grasses and adapted crops, the natural recharge of the aquifer is restricted. Thus, irrigation from groundwater will accelerate the groundwater crisis and result in water-table level declining and groundwater depletion.

One positive method to improve crop production in Kansas is to make more efficient use of the precipitation that is received. Fallowing of land in western Kansas is a proven technique to increase soil moisture for subsequent crops. The typical fallow period is 15 months and, currently, about 30 percent of the precipitation that falls during the fallow period is stored in the rooting zone for subsequent use. However, this amount of water is not enough to result in significant groundwater recharge, because the amount of soil water stored is only about 16 cm per year. Now, one developed idea is that if we lengthen the fallow period from 15 months to 27 months, which is the so-called WHEAT-DOUBLE FALLOW, more water would be available to increase soil moisture. It could greatly increase the probability of exceeding the moisture holding capacity of soil in the rooting zone and drainage of water below the rooting zone and ultimately to the underlying aquifer under this condition would be possible.

Since the stored soil moisture generally adds increments of water that contribute to grain production, the value of such water is important. Data from Akron, Colorado [Koelliker, 1976 (adapted from Mickelson et al. 1974)] show that about 225 mm of total available water (water stored in soil at seeding time + growing season precipitation - runoff) is needed before any grain is produced by wheat. Each additional 25 mm up to a total of 600 mm increases grain yield by about 260 kg/ha (4 bu/ac). In an area where wheat yield on wheat-fallow average 2000 kg/ha every other year, increasing available soil moisture by 95 mm with another year fallow could result in equal grain yield over the long-term by wheat-double fallow. That is to say practicing doubl fallow may not decrease the gross wheat production, but it could greatly increase the groundwater recharge potential.

The purposes of this study are to: 1) verify the concept of double fallow through a field experiment to determine the fallow efficiency and whether movement of soil water below rooting zone would result. The field experiment was conducted in Colby Branch Experiment Station. The soil profile up to 4.5 m (15 ft) in depth was observed in this experiment. 2) design a computer model to simulate soil moisture storage and movement. A newly presented method to calculate unsaturated conductivities from desorption data by L. R. Sinclair (1981) was adapted in this study. and 3) design and modify a continuous water budget model to simulate conditions during wheat-double fallow and use this model to assess the groundwater recharge potential. Two sets of computer programs were designed. One is called short-term model which simulated the period from Aug. 1979 to Aug. 1981. We used this program and field data to calibrate the model. The other one is the long-term model, which is based on the calibrated short-term model and is a refined edition of Neibling's Continuous Water Budget Model (Neibling, 1976).

While the results of the model will not be a positive proof of success or failure of this proposed system, they will provide important indications of how such a system might perform under varying weather conditions not experienced during the 27-month period of the field experiment. Model results can also be helpful in evaluating the potential at other locations in western Kansas.

CHAPTER 2 CONTINUOUS WATER BUDGET MODEL FOR WESTERN KANSAS

In this study, a continuous water budget model, which was developed by Neibling in 1976, is applied. Several necessary modifications have been made to meet the wheat-double fallow conditions. But the basic frame is the same.

(1) Water Budget System

This model is a continuous watershed model with interflow assumed to be negligible and streamflow not calculated. Figure 1 will simply describe the water budget system considered in this model.

Precipitation is the major input of the system. Snowmelt is also considered as an input when winter condition applied. The output of the system will be Actual Evapotranspiration (AET), Interception, Runoff, Snowpack and Deep Percolation. Infiltration is defined as interception, runoff and snowpack subtracted from total input water, which will infiltrate from the earth's surface into soil layers. Sixteen soil layers will be considerd in the model, and from Figure 1, the EXTRA from the fifteenth layer will be treated as deep percolation.

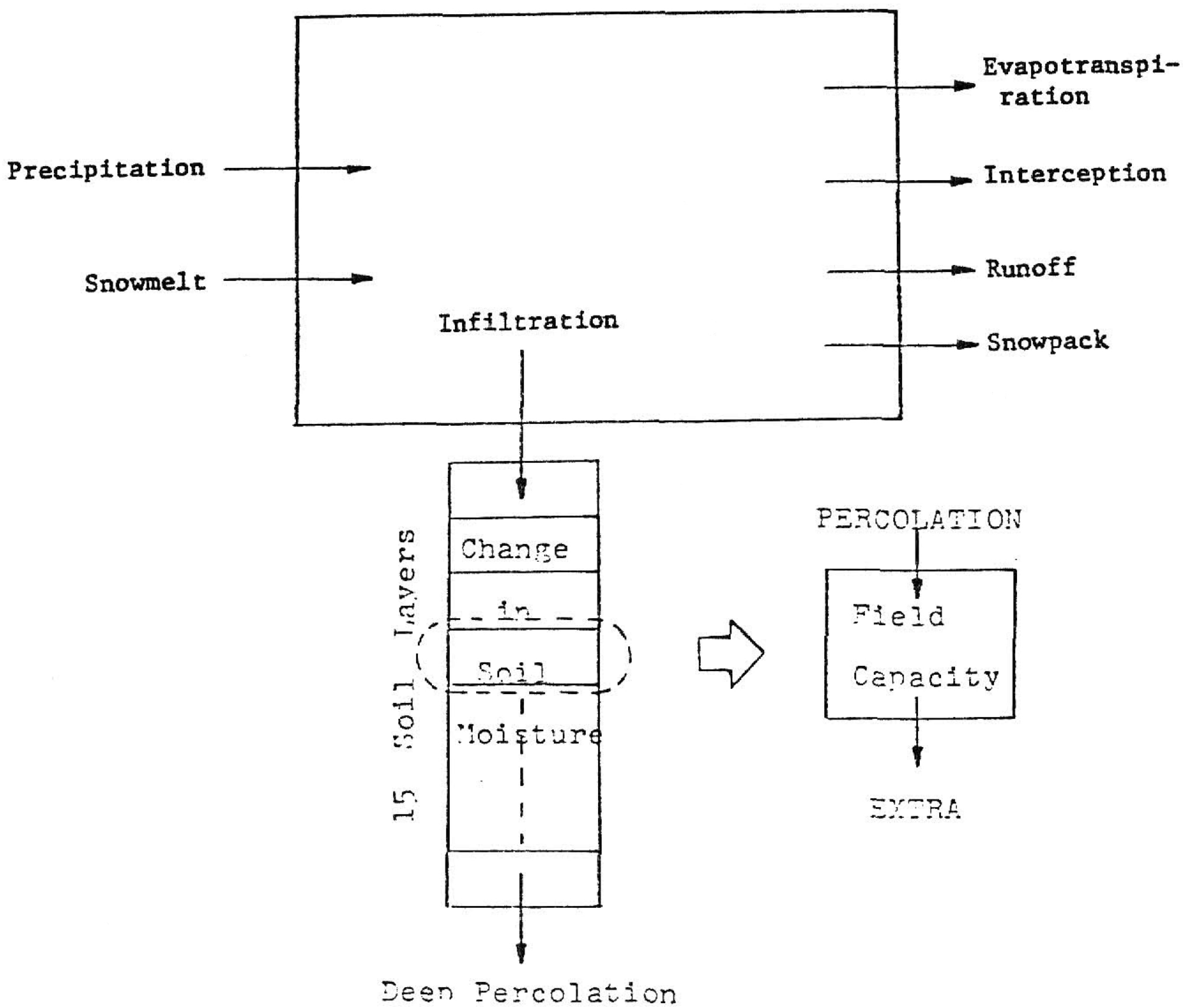


FIGURE 1. Scheme of Water Budget System

(2) Hydrologic Components

The remainder of this chapter is to review the basic theory and principles incorporated in each component of the hydrologic cycle being considered in the model.

1. Evapotranspiration

Transpiration is the loss of water from the stomatal openings in the leaves of plants. When evaluating water loss from a vegetated surface, it is always impossible to separate transpiration and soil evaporation. These two mechanisms are combined and called evapotranspiration, being synonmous with the term consumptive use in agronomy.

When a vetgetated surface is losing water to the atmosphere at a rate unlimited by source of water supply, it is called potential evapotranspiration (PET). If the supply water is limited, actual evapotranspiration may be less than the potential.

Several acceptable methods of computing potential and actual evapotranspiration have been developed and used. The Penman method is one of the most commonly used methods. Penman developed his mathematical expression predicting evapotranspiration from a vegetative cover by using the energy balance and mass transfer theory. The mathematical formula, known as the Penman combination method, was calibrated by Bean (1975) and presented as

$$PET = 0.039\ Ta^{0.637} [\ (1-r)\ Ra\ (\ 0.22 + 0.54\ PSUNS\ ) - 2.010 \times 10^{-9}\ T^{4}\ (\ 0.98 - c - d(ES \times RHD\ )^{0.5}) \times (\ 0.1 + 0.9\ PSUNS\ )\ ] + (\ 1 - 0.039\ Ta^{0.637}\ ) \times 0.26\ (\ e + 0.01\ WVD\ )\ (\ ES - ES \times RHD\ ) \quad (1)$$

where

PET = potential evapotranspiration, in inches

Ta = mean daily air temperature, in degree Fahrenheit

T = mean daily temperature, in degree K

r = reflectance coefficient (albedo)

Ra = solar radiation, in mm of water

PSUNS = percent sunshine, in percent

ES = saturation vapor pressure of a water surface at the Ta, in mb

c, d = empirical coefficient, which can vary geographically. (Brunt c and d)

RHD = relative humidity, in percent

WVD = wind run in miles/day

e = mass transfer coefficient

In most studies, the albedo of water surface is assumed to be constant of r = 0.05, from which PET from free-water surface is obtained. while the albedo for green crops varies from 0.20 to 0.25. The geographic constants of c and d can be determined approximately by using Figure 2 as explained by Zovne and Koelliker (1979), and then can be further refined and calibrated to reflect the actual case at a location by making several runs of the model. The c and d values are changed

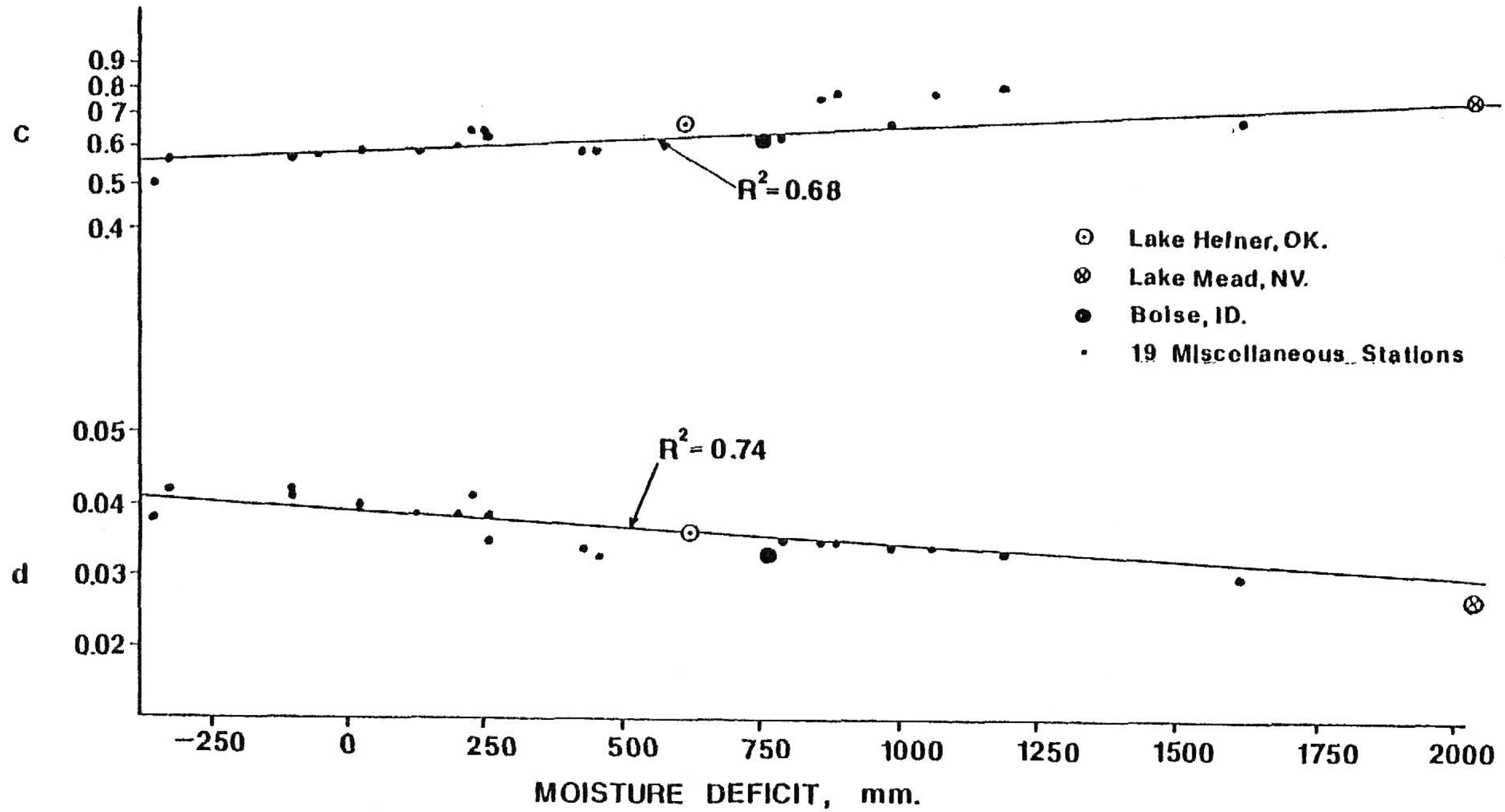


Fig. 2 Relationship of Brunt c and d coefficients to moisture deficit.

slightly until long-term average PET equals average lake evaporation.

The actual evapotranspiration rate is governed by climate, vegetation, and soil factors. When moisture conditions in soil are suitable, the actual rate of evapotranspiration is equal to the potential for either bare soil or vegetated soil. The most common method to estimate actual evapotranspiration is through the calculation of PET. If there is enough water in the soil, the two cases are equal. Otherwise, the potential rate is modified according to the amount of water in the soil as following relationship,

$$AET = PET \times f \, (AW / AWC) \tag{2}$$

where

f = a certain function

AET = actual evapotranspiration

PET = potential evapotranspiration

AW = the available soil moisture

(soil moisture content - PWP) x root profile depth

AWC = available water capacity

= (field capacity - PWP) x root profile depth

PWP = permanent wilting point

The available soil moisture at any time is the amount of water held at a moisture content above the permanent wilting point. The available water capacity is defined as the difference between field capacity and permanent wilting point.

The actual rate of evapotranspiration for either bare or vegetated soil is affected by soil and crop type. Evaporation from bare soil differs in two stages. Stage 1 (constant rate stage) evaporation occurs when the soil is sufficiently wet to readily transport water to the soil surface. To estimate the Stage 1 evaporation, Equation 1 is used for the bare soil condition with r equal to 0.20. In Stage 2 evaporation the hydraulic properties of the soil begin to limit the rate of water transfer to the surface, causing a decrease from the constant rate stage. Ritchie (1972) and Kanemasu (1975) calculate Stage 2 evaporation by

$$E2 = 25.4 \times [\ ct^{0.5} - c(\ t - 1\ )^{0.5}\ ] \qquad (3)$$

where

E2 = Stage 2 evaporation from bare soil surface, mm

c = soil dependent coefficient, $mm/day^{0.5}$

t = time since the beginning of Stage 2 evaporation, day

The value of Stage 2 threshold (U) and of c were obtained from Ritchie (1972) and field experiments at Manhattan, Kansas, by Kanemasu (1975).

Reduction of Stage 1 and 2 evaporation by a developing canopy is calculated by the use of Equation 4

$$Ec = Ei\ (\ t\ /\ a\ ) \qquad (4)$$

where

Ec = soil evaporation corrected for canopy effects

E_i = original uncorrected soil evaporation for

$i = 1$ (Stage 1) and $i = 2$ (Stage 2)

t = a constant, indicating canopy effect

= EXP (- 0.398 x LAI)

a = a calibration constant

LAI = leaf area index

The rate of evapotranspiration of a crop is dependent upon atmospheric, plant, and soil factors. The atmospheric factors are incorporated in computation of PET by the Penman method. A plant consumptive use factor, k, by Blaney-Criddle method is applied to the modification of PET in accounting for a plant factor.

If a vegetated soil surface is considered, Equation 5 is used to calculate evapotranspiration,

$$AET = PET \times k \times AW/0.3\ AWC \qquad (5)$$

where

AET, PET, AW and AWC are previously defined,

k = crop consumptive use coefficient

When the available soil moisture is greater than thirty percent of the maximum available soil moisture, evapotranspiration will occur at the maximum rate of the product of PET and crop consumptive use factor, k. When the soil moisture falls below thirty percent of the maximum available soil moisture, the AET decreases linearly from the maximum rate to zero at the permanent wilting point. The crop coefficients, k, in Equation 5 can be determined by Blaney-Criddle method described in SCS, Technical Release No. 21. When the soil lies fallow, or during the dormant season, the k is zero.

2. Snow

The purpose of snow model is to determine the amount of snowmelt and snowpack formed. The criteria for formation of snowpack is that precipitation events occurring on days having an average termperature $T < 0^oC$ are accumulated as water equivalence of snow.

Snowmelt consists of two parts: snowmelt due to atmospheric conditions and snowmelt due to rainfall. Snowmelt due to atmosphere conditions can be estimated by Equation 6.

$$M = 2.54 \times C \ (Ta - Tb) \quad (6)$$

where

M = snowmelt, in cm

Tb = base temperature, degree Fahrenheit

Ta = mean daily atmospheric temperature, degree Fahrenheit

C = degree-day coefficient

Snowmelt due to rainfall can be estimate by Equation 7.

$$MR = 2.54 \times (1 / 144) (P) (Ta - 20) \quad (7)$$

where

MR = snow melted by rainfall, cm

P = amount of rainfall, inches

Ta = mean daily temperature, degree Fahrenheit

3. Runoff

Surface runoff is calculated by the method developed by the U. S. Soil Conservation Service (SCS).

$$Q = (P - 0.2S)^2 / (P + 0.8S) \qquad (8)$$

where

Q = surface runoff, in cm

P = precipitation, in cm

S = potential maximum difference between precipitation and runoff, in cm

The initial abstraction, IA, consists of interception, infiltration, and surface detention. The empirical relationship is :

$$IA = 0.2S \qquad (9)$$

The unknown parameter S must be established from the soil-cover complex, which relates antecedent moisture conditions, hydrologic soil groups, land use, and conservation practices. For those soil-cover properties, the curve number CN is obtained from Table 1 for Antecedent Moisture Condition II (AMC II). The maximum potential difference, S, can be evaluated by the equation,

TABLE 1 SCS RUNOFF CURVE NUMBERS FOR AMC II

SOIL CLASS	ROW CROPS	ALFALFA	WHEAT	PASTURE	FALLOW
1	86	83	84	80	84
2	86	83	84	80	84
3	82	83	81	74	78
4	82	83	81	74	78
5	75	69	73	61	69
6	75	69	73	61	69
7	75	69	73	61	69
8	75	69	73	61	69
9	75	69	73	61	69
10	75	69	73	61	69
11	75	69	73	61	69
12	65	55	61	39	61

AMC II - During the growing season, soil moisture in the top 1 ft is between 0.5 and 0.8 of field capacity, or for the non-growing season, 0.6 to 0.9 of field capacity (FC).

AMC I - Occurs when soil moiture less than 0.5 (0.6) FC.

AMC III- Occurs when soil moisture greater than 0.8 (0.9) FC.

$$S = 2.54 \times (1000 / CN - 10) \tag{10}$$

where

S = maximum potential difference, in cm

CN = runoff curve number (AMC II)

The input CN is based on antecedent moisture condition two. The CN is modified for other moisture conditions as follow :

For AMC I,

$$CNi = CN \times 0.39 \times EXP (0.009 \times CN) \tag{11}$$

For AMC III,

$$CNiii = CN \times 1.95 \times EXP (-0.00663 \times CN) \tag{12}$$

4. Interception

Interception-storage losses are defined here as the amount of precipitation that is evaporated back to the atmosphere from the surface of plant leaves and/or surface storage.

An effective approach for computer simulation of these losses involves fixing an interception-storage capacity (Saxton et al. 1974, Ward 1975), which must be satisfied before water from precipitation or snowmelt is available for infiltration or runoff.

Interception-storage losses are evaluated and assumed to be lost by evaporation at the potential rate. If no precipitation occurs the previous day, or if all previous interception losses have been evaporated, these losses are assumed to be 2.5 mm for rainfall amounts exceeding 2.5 mm and equal to precipitation for lesser amounts (Anderson 1975, Saxton et al, 1974). If precipitation occurs the previous day, or if any water is present in the interception-storage account, available interception-storage is first reduced by this amount before being deducted from precipitation.

5. Infiltration and Soil Moisture Movement

Any rainfall or snowmelt not lost by runoff or interception-storage is assumed to enter the soil profile as infiltration, filling the top 15 cm to field capacity. Any remaining moisture moves downward, filling each succeeding layer to field capacity until all the moisture available for increasing soil moisture is depleted. Any moisture passing from the 3.9 - 4.2 m layer to the 4.2 - 4.5 m layer is assumed to be ultimately used for groundwater recharge. Similar approaches were used by Saxton (1974) and Neibling (1976). The only difference was that they assumed moisture passing from 152 - 183 cm layer to the 183 - 213 cm layer as the groundwater recharge.

The soil moisture-unsaturated hydraulic conductivity relationships used in Neibling's model were obtained using Doering's One-Step Method. In this model, however, a method presented by L. R. Sinclair (1981) which derives conductivities from desorption data is used. Further description of this method will be presented in Chapter 3.

Potential groundwater recharge is calculated as the sum of recharge due to water entering the 4.2 - 4.5 m (14 -15 ft) layer from heavy rainfall and the movement of water across the 4.2 m (14 ft) depth, downward taken as positive, as calculated by the Darcy Equation. The 4.2 -4.5 m layer is allowed to seek its own moisture level. This gives a realistic set of conditions for moisture flow across the 4.2 m boundary. Negative deep percolation values indicate soil moisture movement upward across the boundary from a moist 4.2 - 4.5 m layer to a drier 3.9 - 4.2 m (13 - 14 ft) layer.

CHAPTER 3 CASE STUDY IN COLBY

The method used to achieve the goal of this study is simple. The procedures used can be devided into two catagories : (1) Field Experiment and (2) Computer Model Simulation. Several field plots were established to experience double fallow and three different tillage treatments were used on the field. However, only one treatment, Chemical, No-till, 8K, was studied in this research. Herbicides were applied as necessary to control all weeds. The initial amount of residue on the surface was 8,000 kg/ha (5,000 kg/ha of original + 3,000 kg/ha of additional baled straw). Field data included soil moisture contents which were collected 13 times during the 25-month research period and amounts of residue remaining on the surface. Soil samples from the various layers were taken to the laboratory for further information on Soil Tension - Moisture Content relationships. By using these data and meteorological data from the Colby Branch Experiment Station located 1 km ENE of the plots, a continuous water budget model was calibrated. Two sets of computer runs were used. One, a short-term model which simulates the field experimental period, was calibrated based on the field data. Then a long-term model, which is based on the calibrated short-term model, was developed. By using this model, we may assess the recharge potential over a long term.

(1) Field Experiment

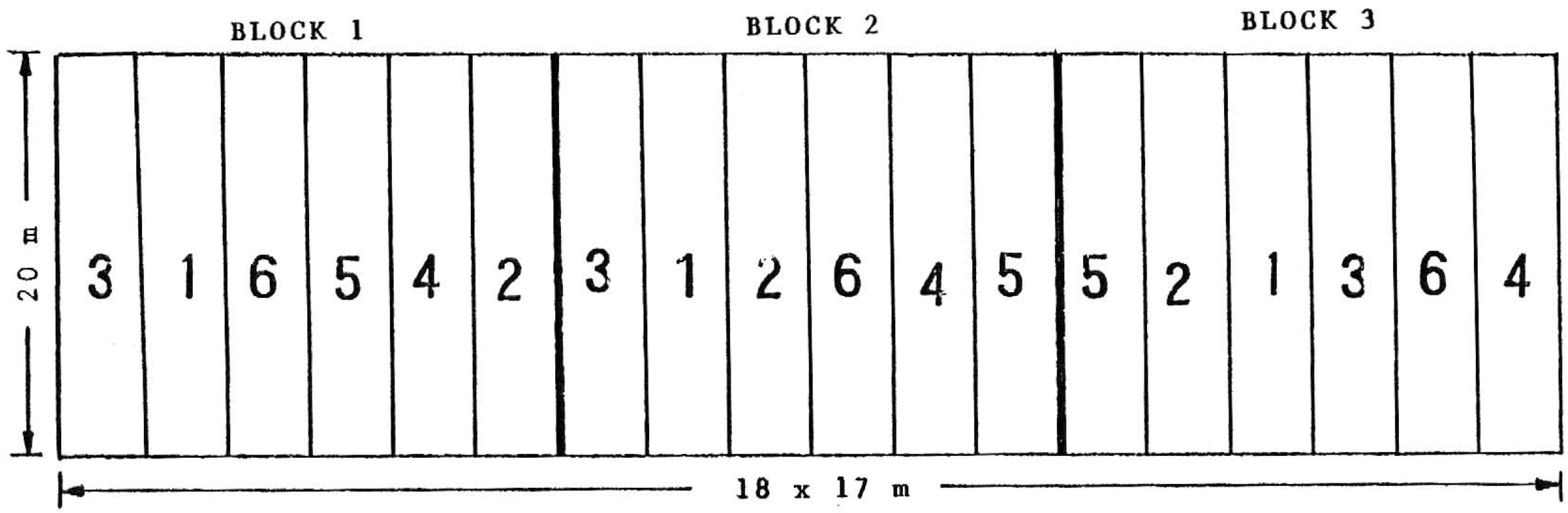
1. Layout

The field experiment was located at the Colby Branch Experiment Station, Colby, Kansas (39° 23' N Latitude, 101° 04' Longitude). The climate of Colby is of semi-arid. It has warm summer and cold winter. The average annual temperature is about 28.6 °C. The average lake evaporation is 142.2 cm/year. The average annual precipitation is 47.6 cm and most precipitation occurs during the growing season (April - September). Field plots were established August, 1979, by Dr. Koelliker in cooperation with Mr. Freddie Lamm, Research Engineer at the Station. The plots were on a Keith silt loam soil which had an approximate 1 percent slope. The plots were positioned so that they would receive very little runoff from the surrounding area and water would flow across the plots such that they all should receive the same treatment. Plots were permanently staked with no space left between the plots. The primary concern was soil moisture measurement, which was made only at the center of each plot, so border effects were not a factor. Each plot was 17 m wide and 20 m long. Six treatments, three tillage (Chemical no-till, Stubble Mulch and Deep Chiesling) by two residue (8,000 kg/ha and 5,000 kg/ha), were randomized within three blocks to minimize biases due to effects of field variation. Figure 3 shows the layout of field experiment.

2. Data Collection

1) Soil Moisture Content

A neutron probe (Campbell Pacific Nuclear model 503



Treatment No.	Descriptions
1	Chemical, No-till, 8K
2	Chemical, No-till, 5K
3	Conventional, 8K
4	Conventional, 5K
5	Chisel, 8K
6	Chisel, 5K

FIGURE 3. Schematic Diagram of Layout of Field Experiment

Hydroprobe) was used in the field to measure the soil moisture contents. Measurements were made at depth 0.3 m to 4.5 m at 0.3 m intervals. Shield counts were recorded in the field, and then the following formula was used to obtain the soil moisture content by volume.

$$SM = 0.2854CR - 0.03834 \qquad (13)$$

where

SM = soil moisture content by volume

CR = count in the soil shield count

2) Soil Sampling

For each experimental site, a soil profile up to 4.5 m was observed. Eight sample cores at different depths were taken from this profile. The size of a sample core was 7.62 cm (3 in.) in length and 7.62 cm in diameter. In this model study, the soil profile is divided into 16 layers, 15.24 cm (0.5 ft) in depth each for the first two layers and 30.48 cm (1 ft) in depth for the subsequent layers. Table 2 indicates the corresponding soil cores used to represent the various soil layers. These sample cores were tested in the Laboratory, Department of Civil Engineering, KSU, by Dianne Smith, Technician at the Department, to provide the information on Field Capacity (FC), Permanent Wilting Point (PWP) and Soil Tension - Moisture Content relationships. When soil tension equaled 15 bars, the soil moisture measured was taken as PWP, and FC, when soil tension equaled 1/3 bar.

3) Residue Data

TABLE 2 CORRESPONDENCE OF SAMPLE CORES AND SOIL LAYERS

SAMPLE DEPTH (in cm)	REPRESENT DEPTH (in cm)	CORRESPONDING LAYER	FIELD CAPACITY (% by volume)	PERMANENT WILTING POINT (% by volume)	As
7.62 - 15.24	0.00 - 15.24	1	29.67	9.83	1.20
22.86 - 30.48	15.20 - 30.48	2	32.33	10.08	1.20
76.20 - 83.82	30.48 - 91.44	3,4	32.17	10.00	1.15
99.06 - 106.68	99.44 - 121.92	5	30.00	6.33	1.12
119.38 - 127.00	121.92 - 152.40	6	25.83	6.83	1.14
144.78 - 152.40	152.40 - 182.88	7	25.00	4.75	1.20
190.50 - 198.12	182.88 - 335.28	8 - 12	25.00	10.08	1.30
342.90 - 350.52	335.28 - 365.76	13	25.00	10.08	1.20
381.00 - 388.62	365.76 - 396.24	14	25.00	10.08	1.25
411.48 - 419.10	396.24 - 426.72	15	25.00	10.08	1.26
441.96 - 449.58	426.72 - 457.20	16	25.00	10.58	1.10

The amount of residue remaining on the field plots was checked three times during the experimental period. All above-ground residue was harvested from 1 m plots and dried. The amount of dry residue in kg/ha was reported. These data provided the information to calculate the Residue Efficiency.

4) Meteorological Data

The meteorological data collected from Colby Station (25-1699-01) provided the necessary weather information to the computer model. The following daily information was available from the Colby Station:

Temperature : Maximum and Minimum

Precipitation

Solar Radiation

Wet-bulb Temperature, 8 am

Windrun

(2) Model Calibration

1. Short-term Model

This is a simplified model with only the fallow condition

considered in this model. Meteorological data used in this model included : daily temperature (maximum and minimum), daily precipitation, daily solar radiation, daily wind runs and mean monthly solar radiation. The water budget system was described in Chapter 2. The major modifications of this model from Neibling's model were : (1) Routine for Double Fallow, Residue Level Estimation (2) PET calculation, and (3) Unsaturated

Hydraulic Conductivity Estimaticn. Several minor modifications are also made to meet the water budget balance requirements and model calibration purpose, such as snow and interception-storage corection and runoff calibration. The calibration results will be presented in Chapter 4.

1) Routine for Double Fallow, Residue Level Estimation

To create a routine for double fallow, the major part was to calculate the residue efficiency. This was accomplished by using the field residue data. Two residue decay stages were observed in the field and the residue was assumed to decrease linearly over each stage. Figure 4 shows the residue decay patterns. The original residue rate applied was about 8K (8,000 kg/ha), and 1K is assumed at the end of fallow period. The field observations provided the information to determine the residue decay pattern.

Figure 5 shows the relationship between Residue Level and Stage 1 Evapcration Efficiency, which was derived based on the figure presented by Bond and Willis (1969). Then combined with Figure 4, the residue efficiencies for the twc residue-level decay stages can be obtained. For the first stage (from wheat harvest tc 365th day of fallow), the residual efficiency was estimated by Equation 14,

$$REFF = ((365 - FADY)/365) \times 0.02 + 0.79 \qquad (14)$$

For the second stage, the residual effiency was estimated by Equaticn 15,

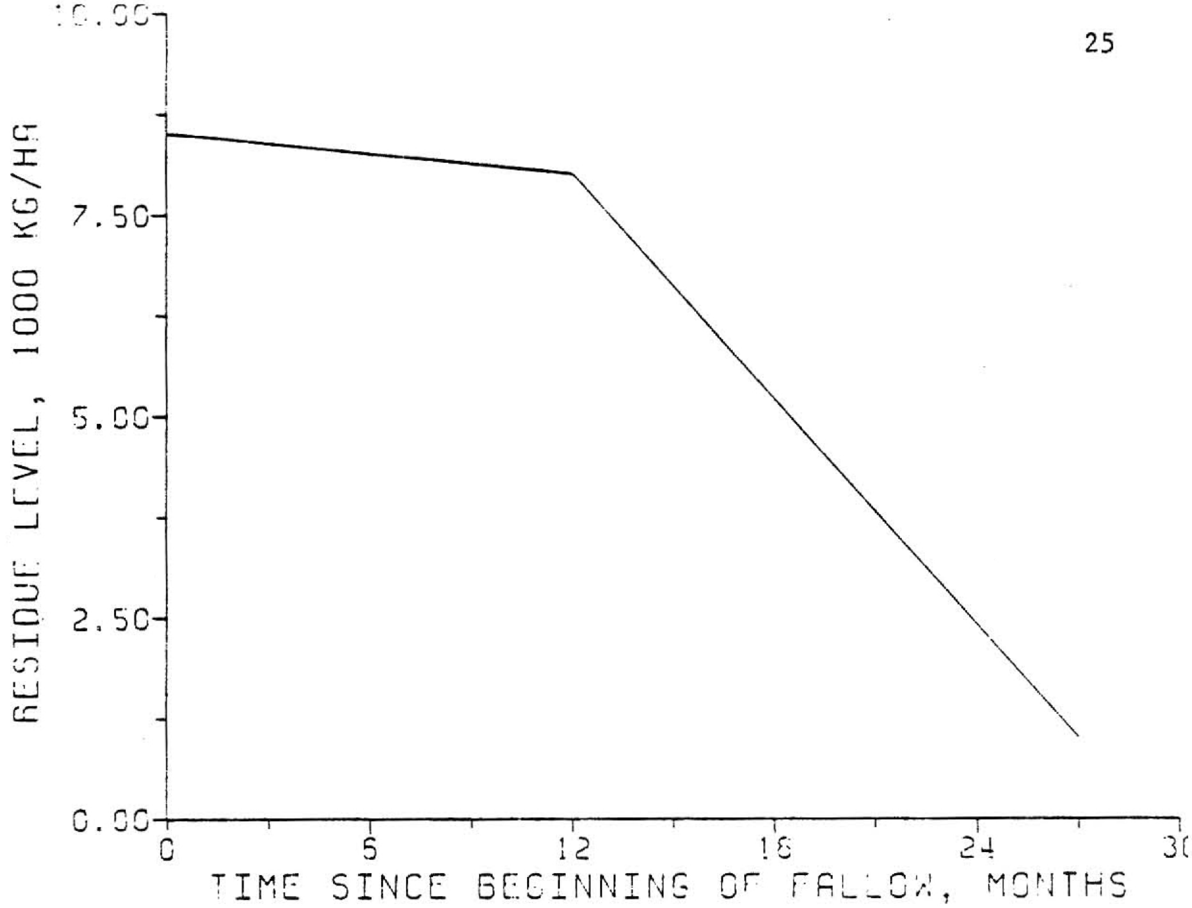


FIGURE 4. Residue Level Decay Patterns

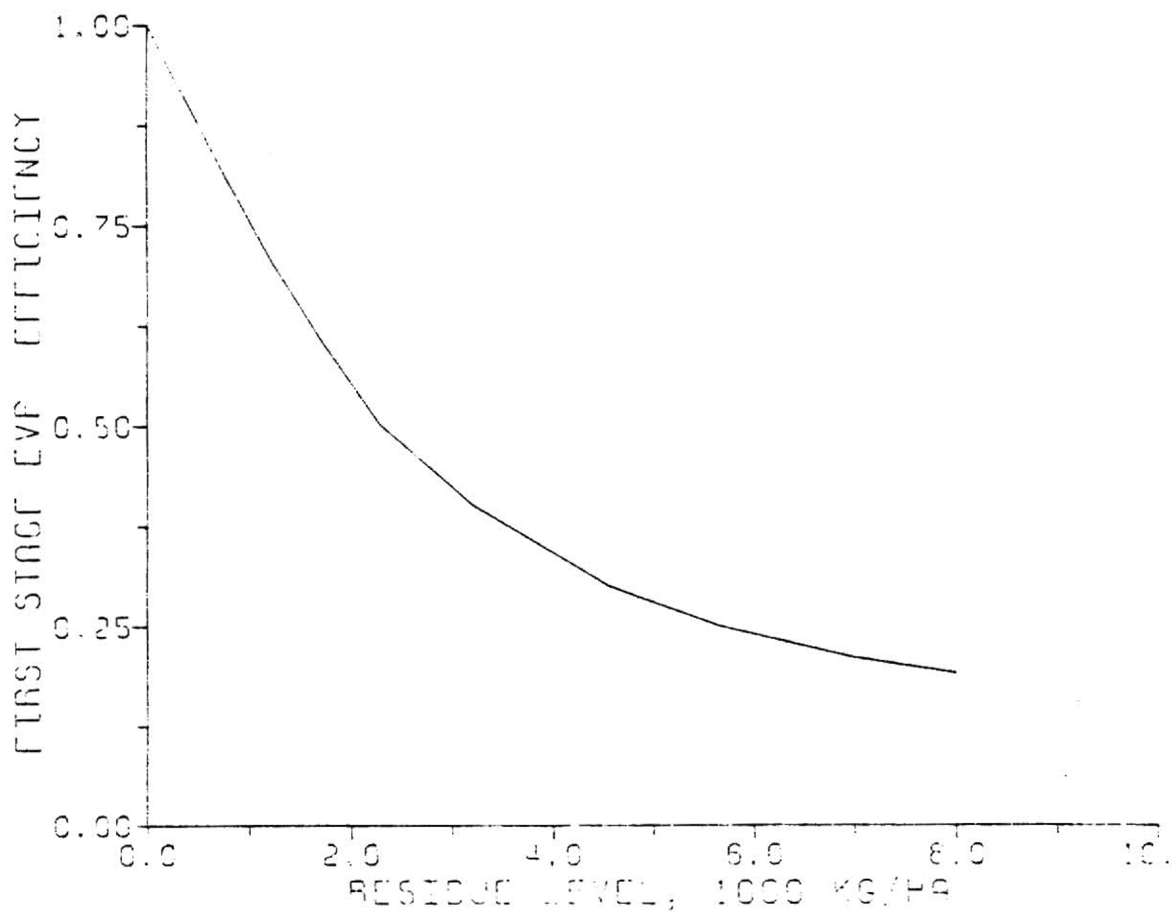


FIGURE 5. Relationship of First Stage Evaporatio Efficiency And Residue Level

$$REFF = ((802 - FDAY)/802) \times 0.55 + 0.24 \quad (15)$$

where

REFF = residual efficiency

FDAY = number of days since fallow began

2) PET Calculation

Because daily observed meteorological data were used instead of using the mean monthly data, and daily solar radiation values were used instead of mean monthly percent sunshine, another form of Penman combination equation was applied to fit the different inputs. A method summarized by Shih et al. (1981). meets the requirements.

$$RN = RS \times (1 - R) - B \times (0.56 - 0.092 \times ESA^{0.5}) \times (0.1 + 0.9 \times S) \quad (16)$$

$$S = 1.818 \times [\, RS/RA(m) \,] - 0.327 \quad (17)$$

where

RN = daily calculated net radiation in mm water

RS = measured daily solar radiation

RA(m) = monthly average solar radiation

R = reflection coefficient

B = Stefan-Boltzman constant

S = estimated ratio of actual duration of bright sunshine to maximum possible duration of bright sunshine

ESA = daily calculated actual vapor pressure (mb)

Anschutz et al. (1979), however, found good agreement between potential evapotranspiration (PET) calculated using monthly averages of percent sunshine, relative humidity and wind speed as oppsed to PET calculated using actual daily values of these same variables when comparing PET over 5-day periods. Due to lack of available data, this PET modification to use daily data for all values could only be used in short-term model. For long-term model, the original equations which used the mean monthly meteorological data as input datawe were used. This gives the model more flexibility and widespread application.

3) Unsaturated Hydraulic Conductivity Estimation

One of the most difficult characteristics involved in modeling soil water movement above the water table is to determine the unsaturated hydraulic conductivity. Direct measurements on undisturbed soil samples in the laboratory and in situ measurements are costly and time consuming. A method, which was developed by Sinclair (1981) for calculating the hydraulic conductivity (K) from desorption data, which are much easier to obtain, was adapted to provide K's for use in our model. According to Sinclair, method gives excellent agreement with measured unsaturated hydraulic conductivity. Based on our calibration results (Figure 8), the method also proved to be a good method for this work.

The basic principles used to derive this method are Poiseuille's Law and Darcy's Law. The theoretical derivation was well presented by Sirclair (1981) and was adapted in Appendix A.

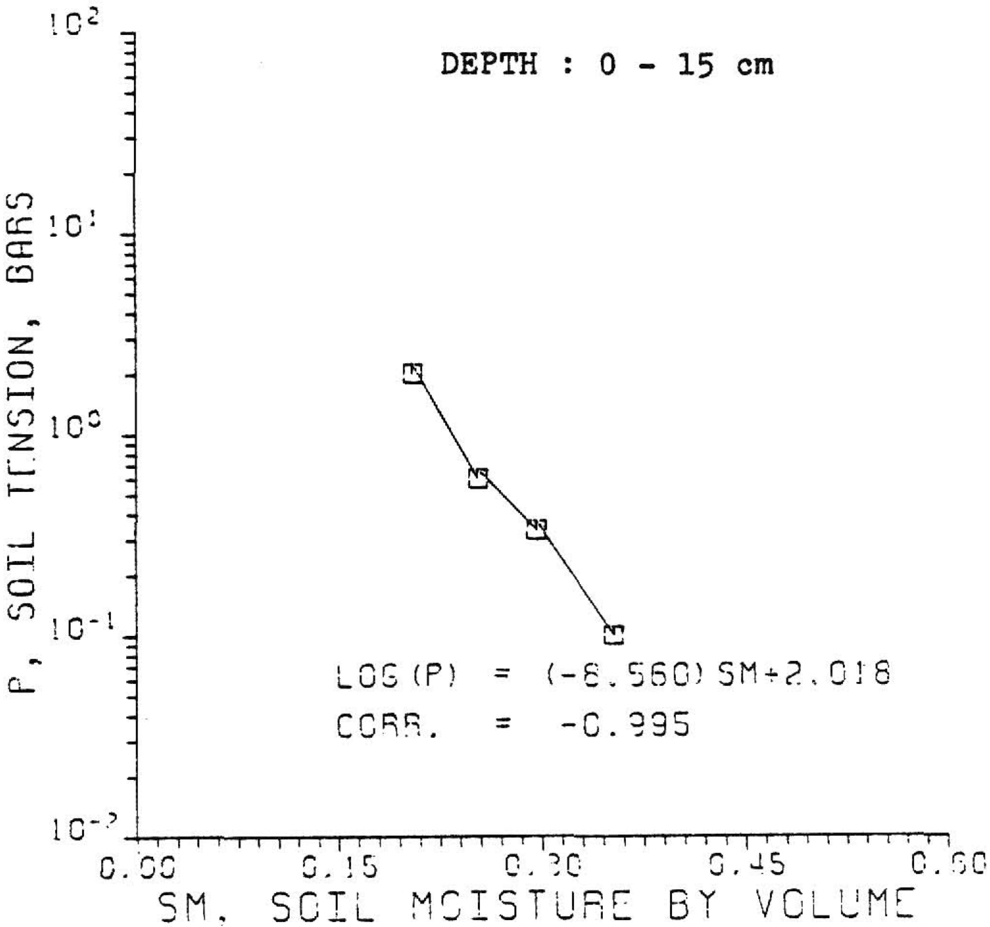
The procedure for applying this method to calculate unsaturated K for each soil layer was also listed in Appendix A. A FORTRAN program was designed to carry out the procedure. The required input information for each soil layer including : the slope and intercept of the regressional curve derived through the descrption data (Figure 6), saturation soil moisture content and residual saturation.

The program was listed in Appendix A-II. Figure 7 shows the results from this program. The relationship between relative conductivity and relative saturation was derived. Then by this relaticnship and definition of Kr (Kr = K/Ks, where K = unsaturated hydraulic conductivity and Ks = saturated hydraulic conductivity. In this study, Ks is assumed to be constant, = 10 cm/day.) and Sr (Sr = SM/SAT, where SM = soil moisture content and SAT = saturation soil moisture content), we can get the relationship between unsaturated conductivity and soil moisture content.

2. Long-term Model

Long-term model was refined based on the calibrated short-term model. Originally, there were four kinds of crop rotations considered in the model, i.e. continuous grain sorghum, continuous wheat, grain sorghum-fallow and wheat-fallow. This study added the fifth option, wheat-double fallow, into this model.

Because lenthening the fallow period was assumed to have no effect on crop canopy effect and root extraction patterns, the original rooting zone extraction patterns and canopy effect functions were used during the crop growing season. In this long-term wheat double fallow study, for each wheat-double fallow period, the 190th day (July 9) of the first year was assumed to be the first day (September 14) of fallow and 257th day of the third year was assumed to be the end of fallow. The long-term model was listed in APPENDIX D and the summary of the long-term run can be found in APPENDIX E.



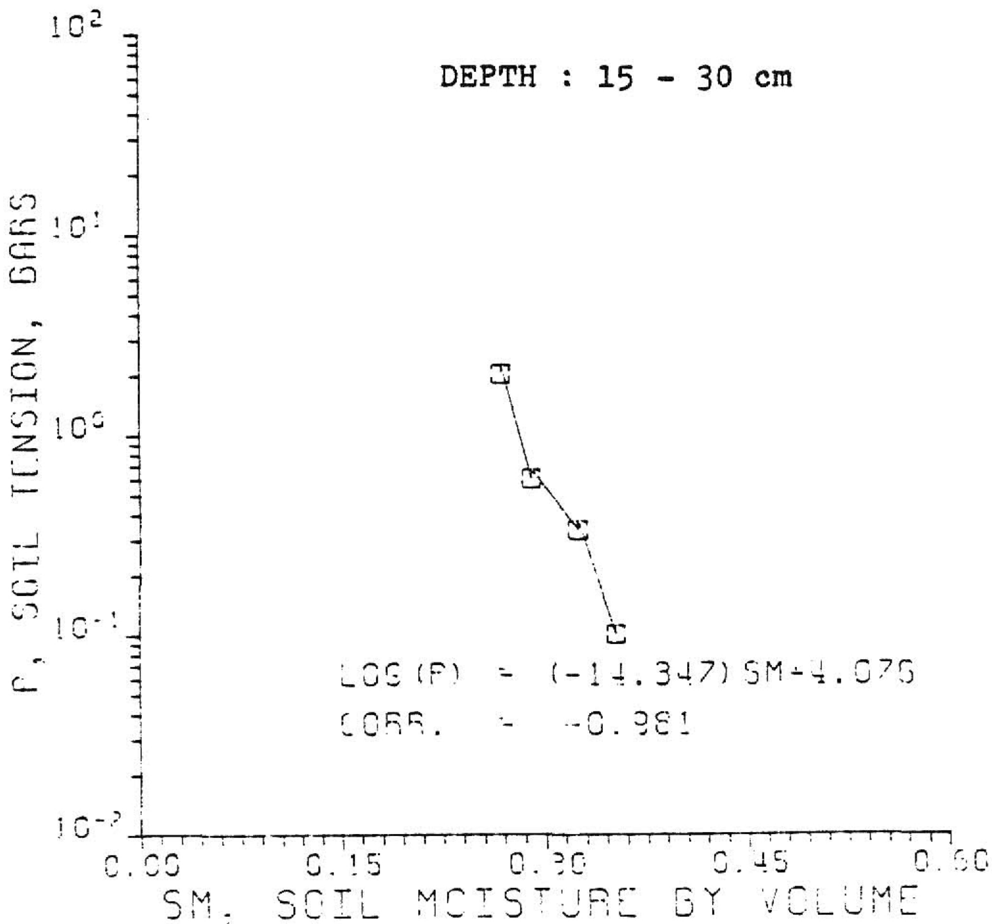
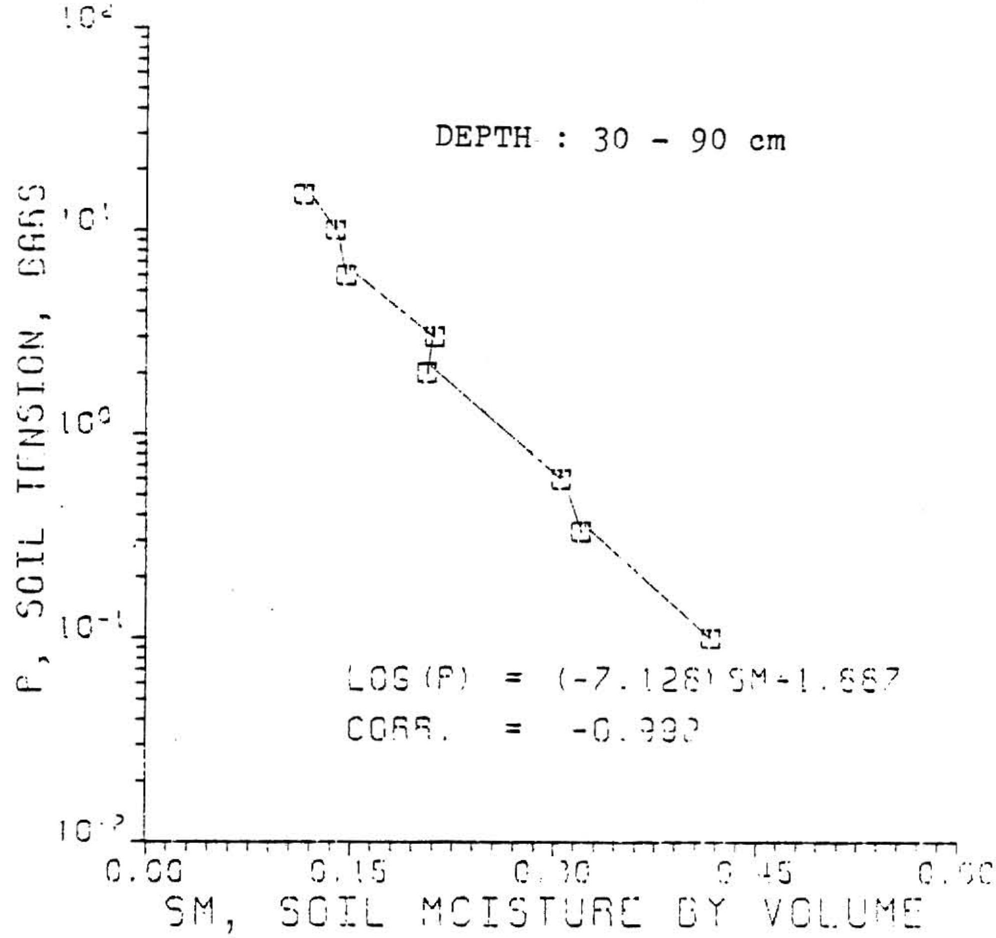


FIGURE 6. Relationship of Soil Tension And Soil Moisture Contents



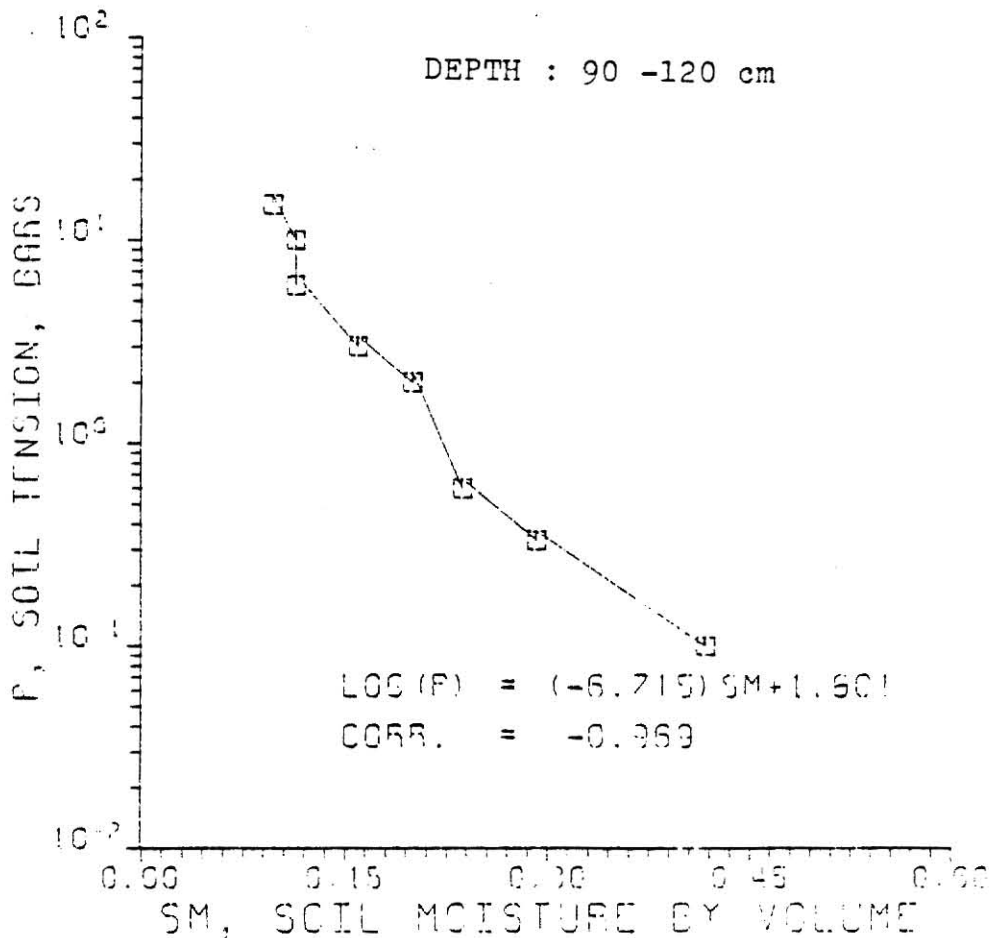
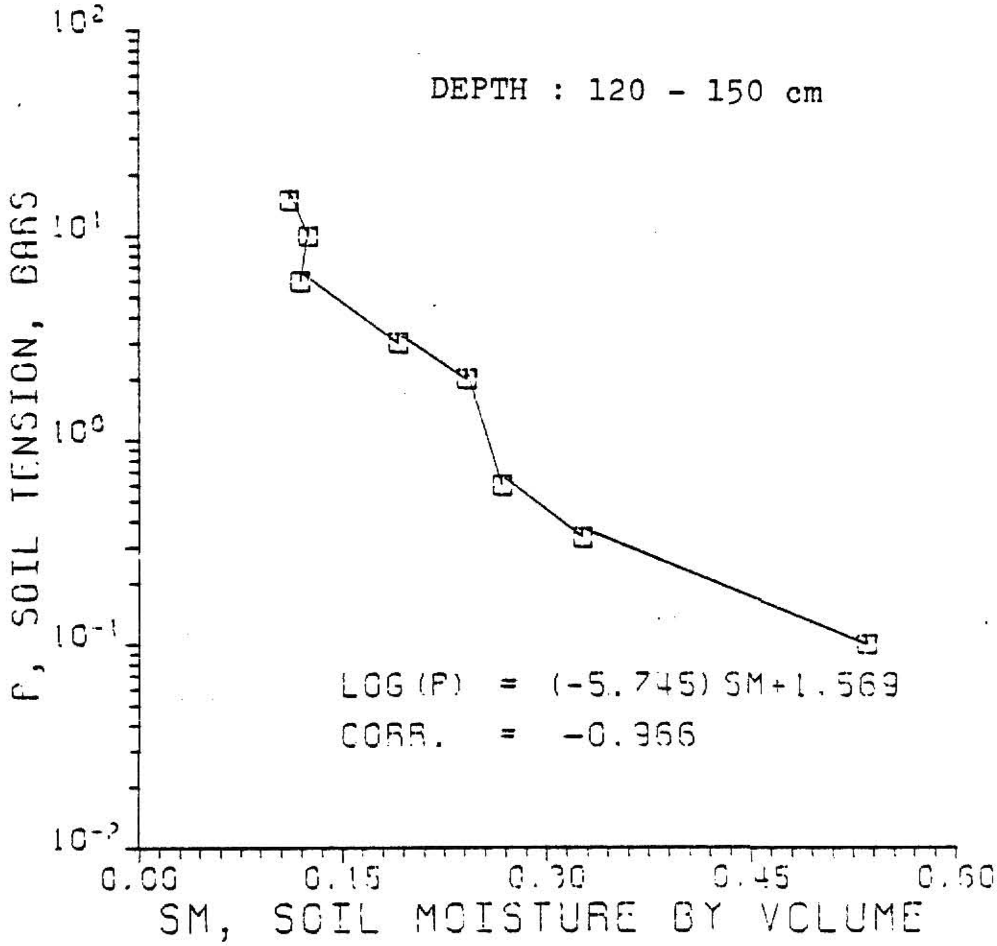
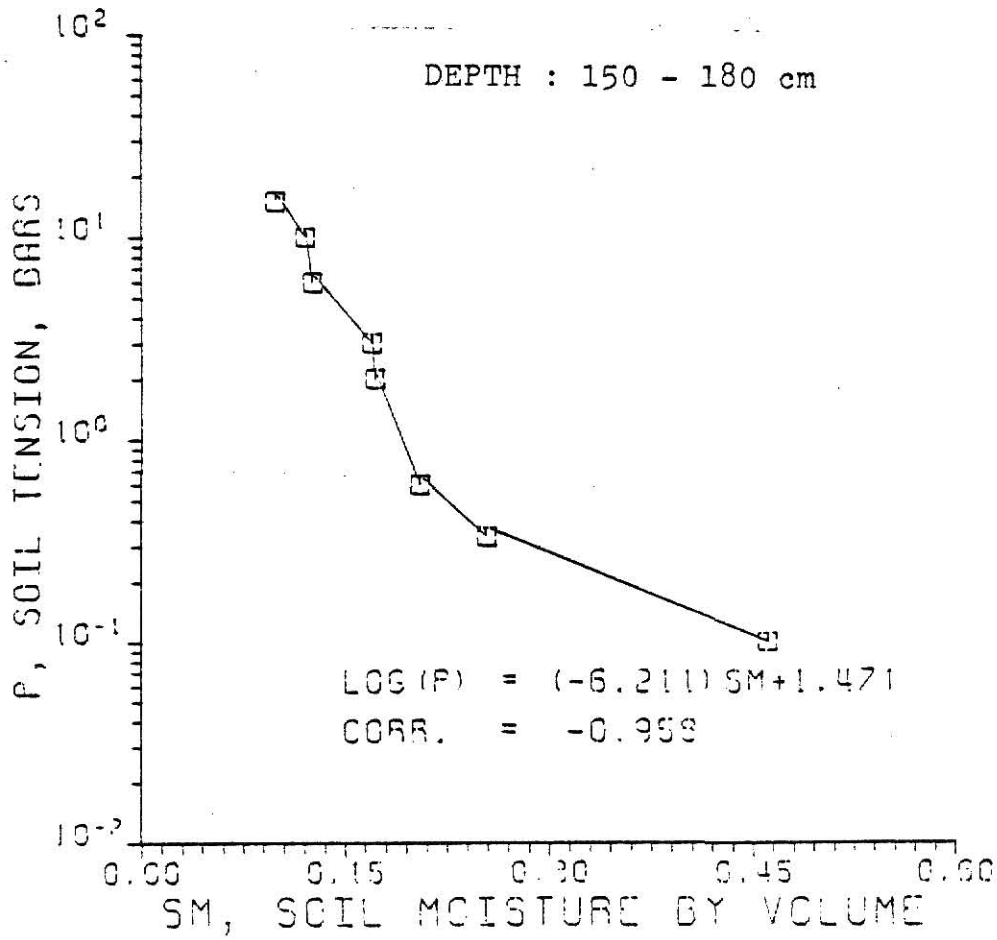


FIGURE 6. (cont'd)





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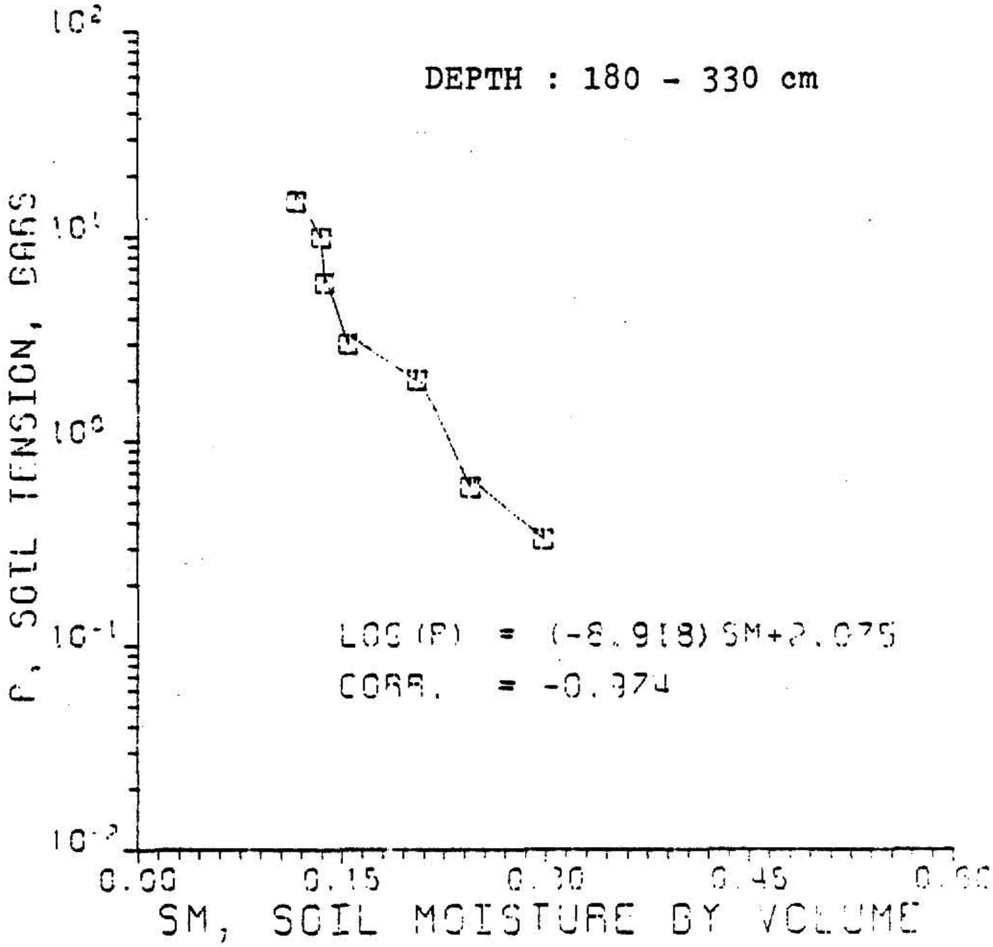

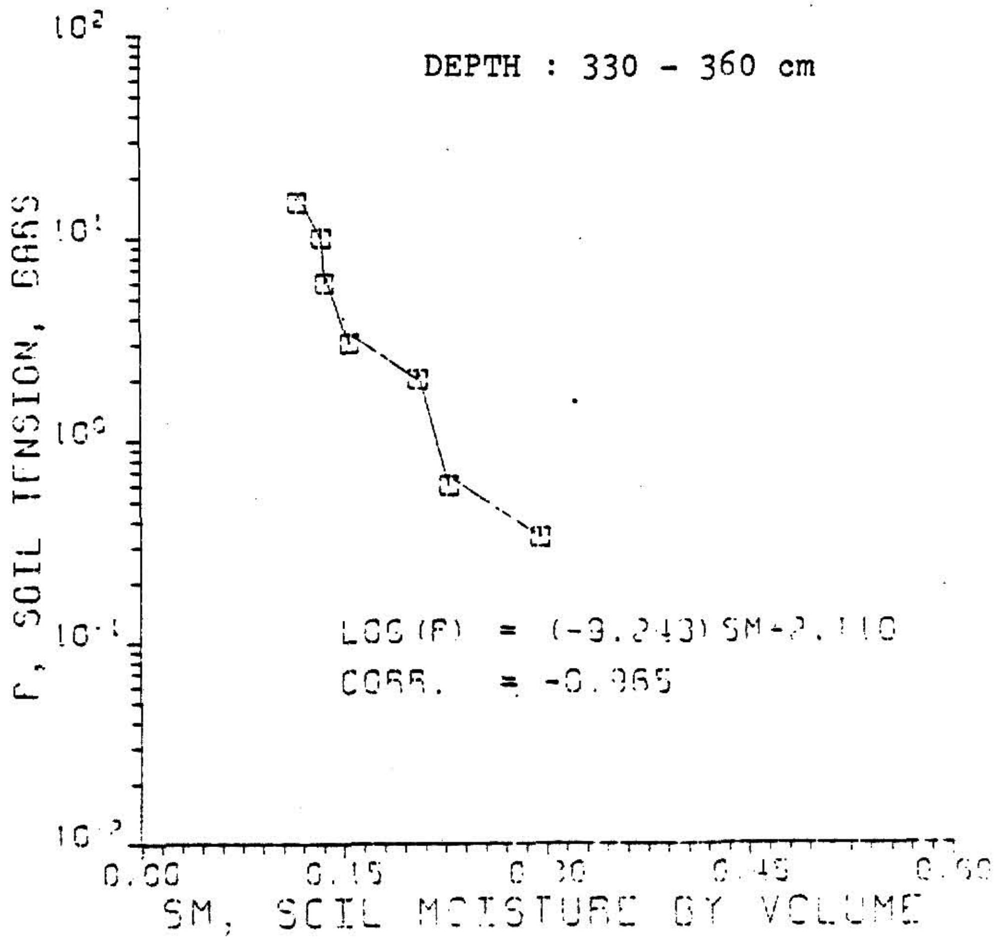

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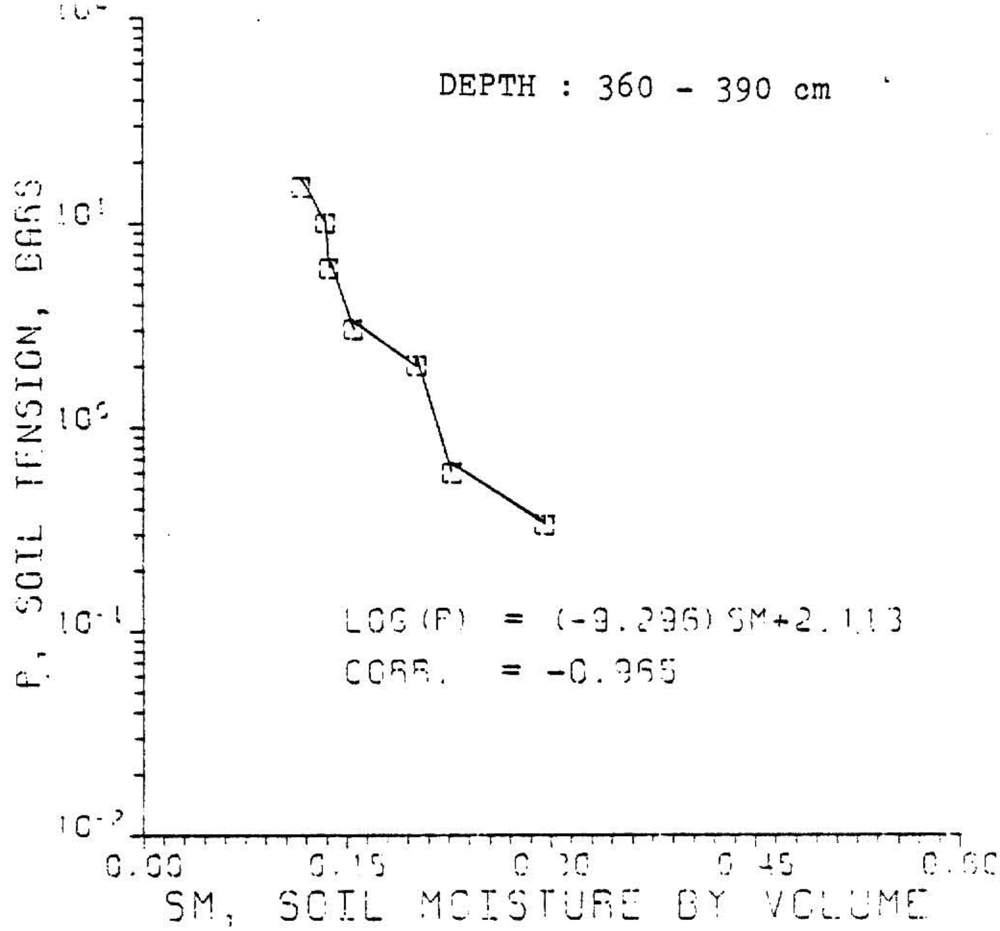


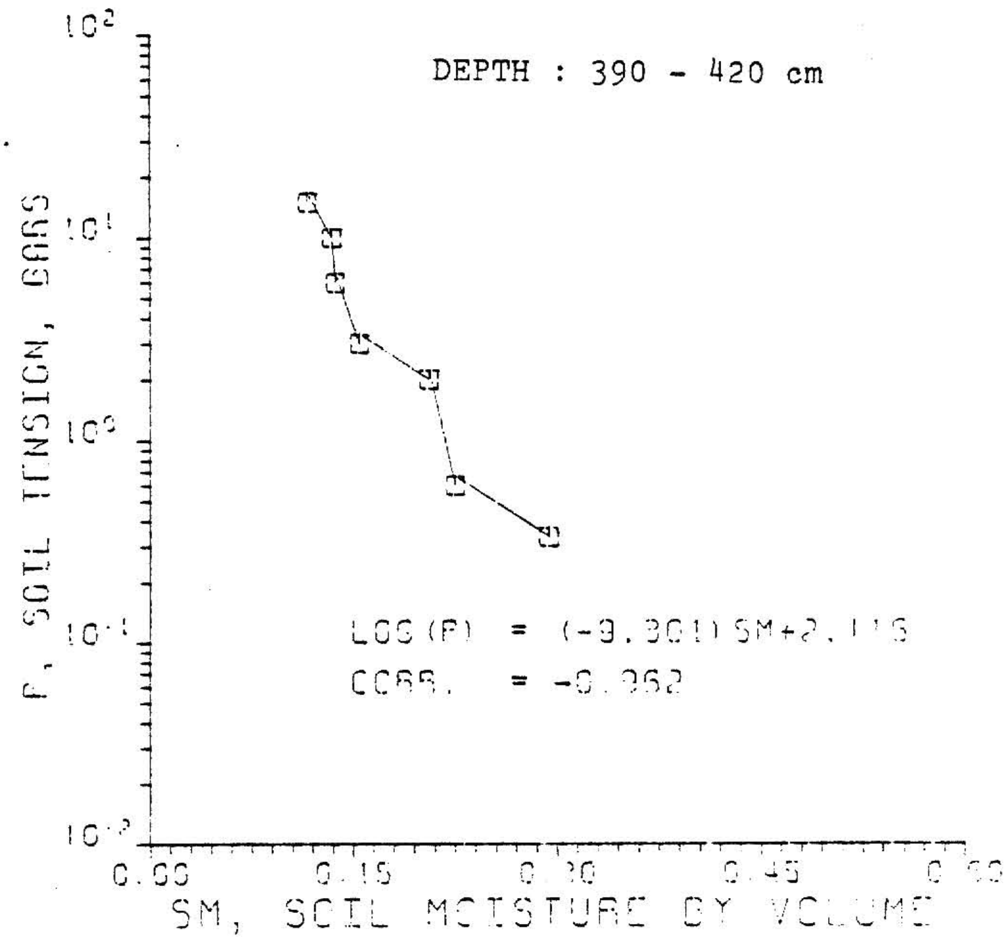
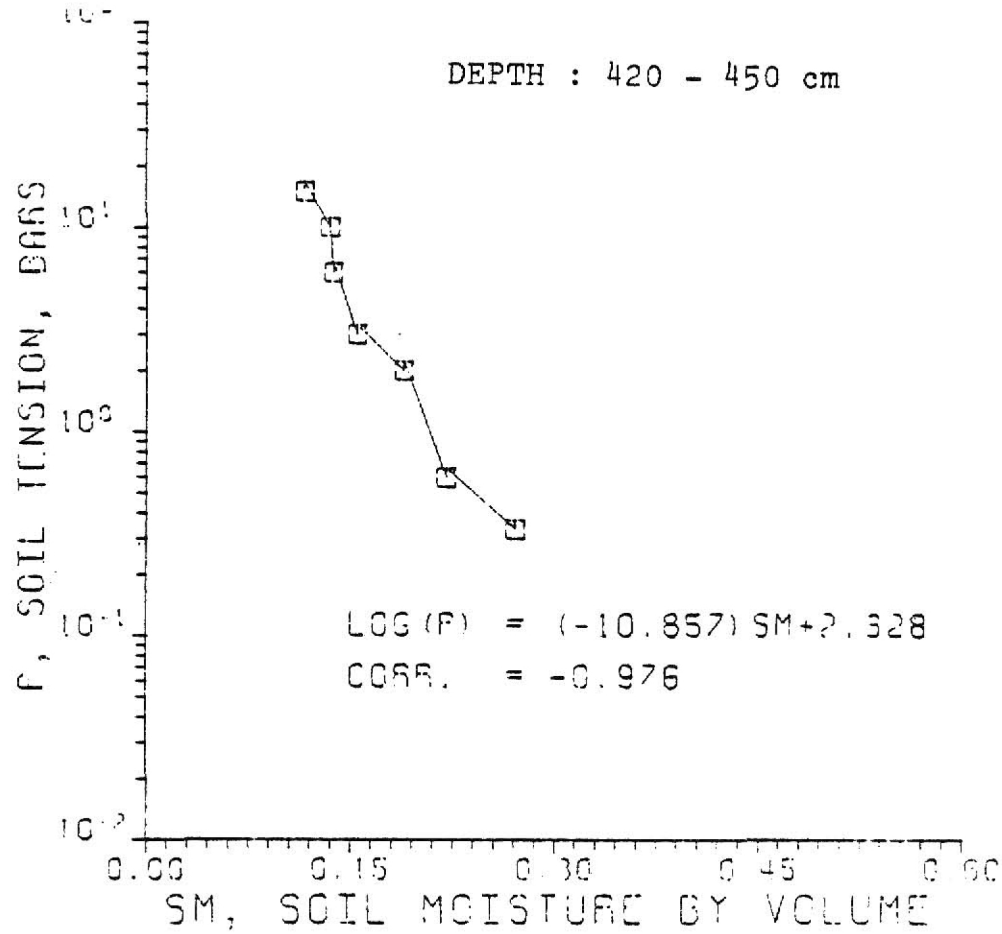


FIGURE 6. (cont'd)



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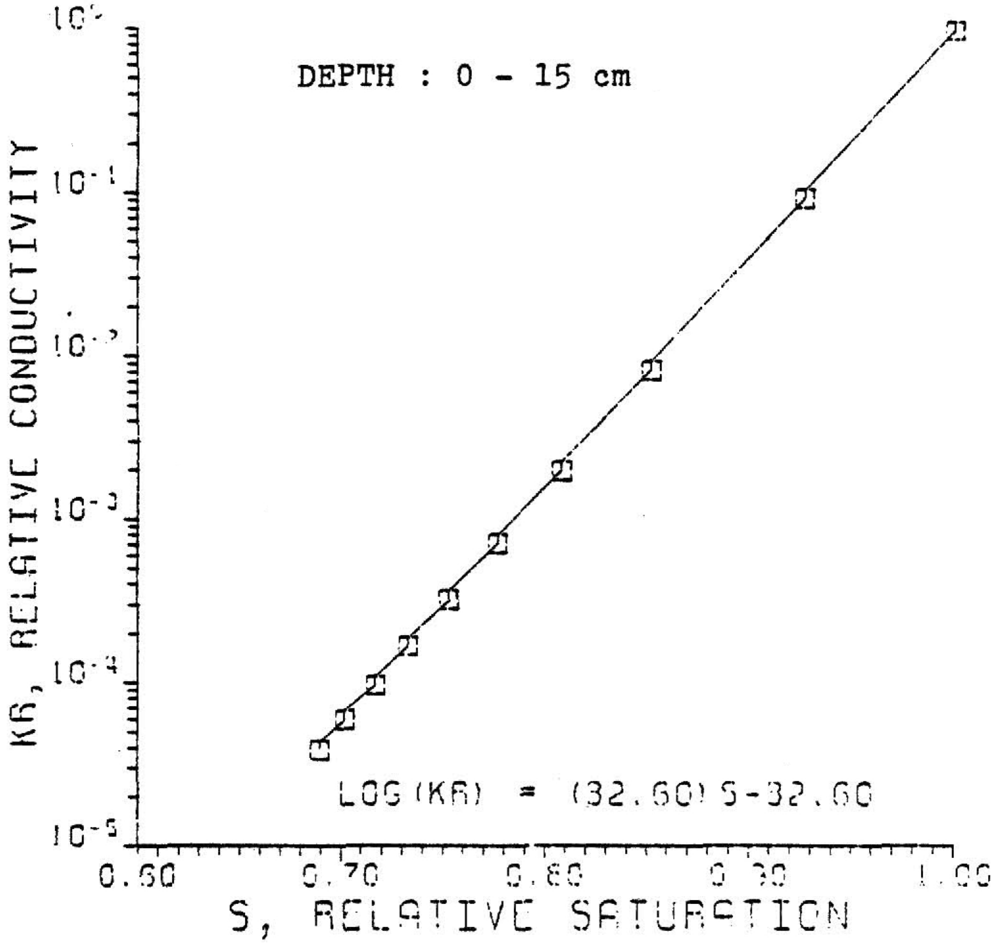


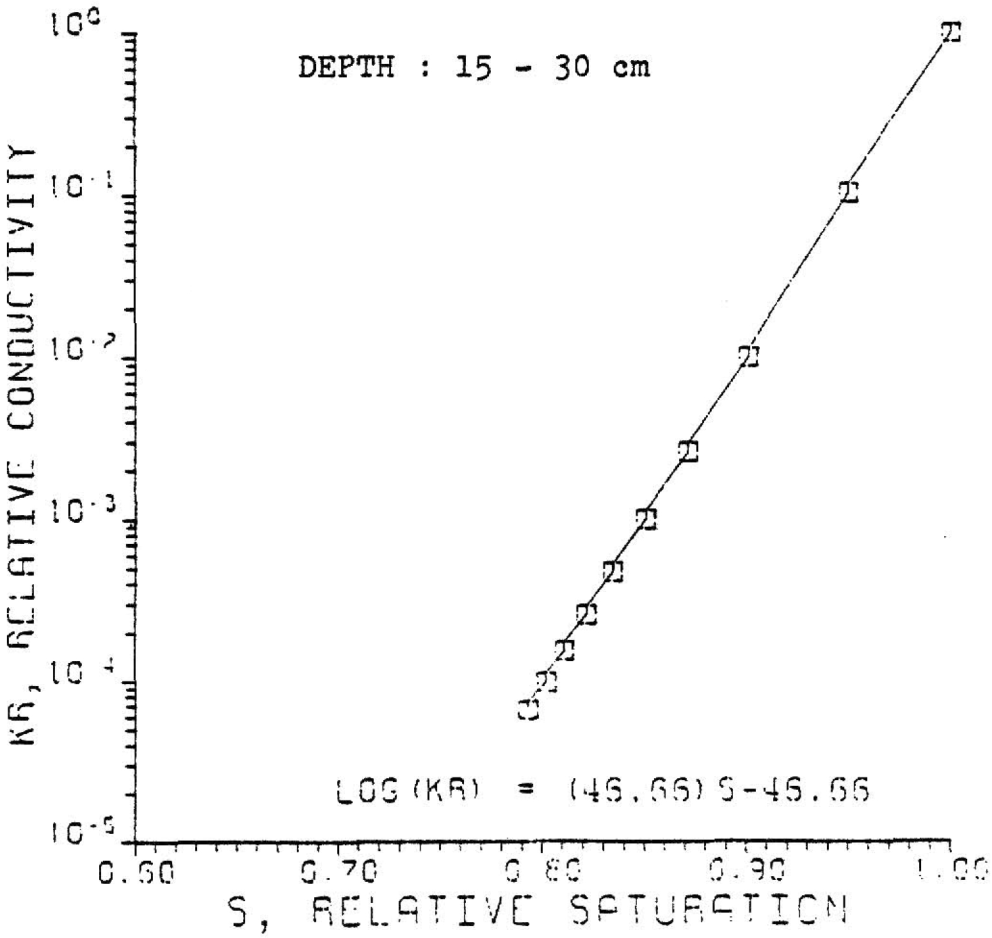
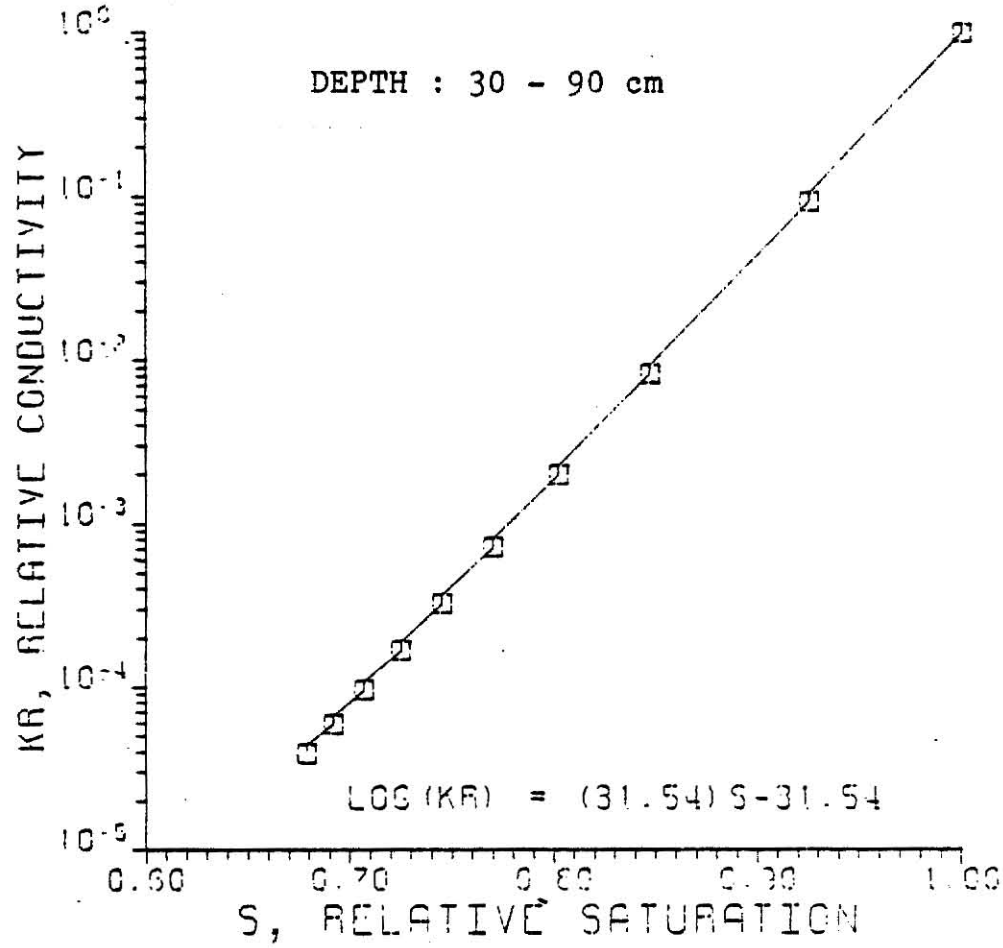


FIGURE 7. Relationship of Relative Conductivity And Relative Saturation



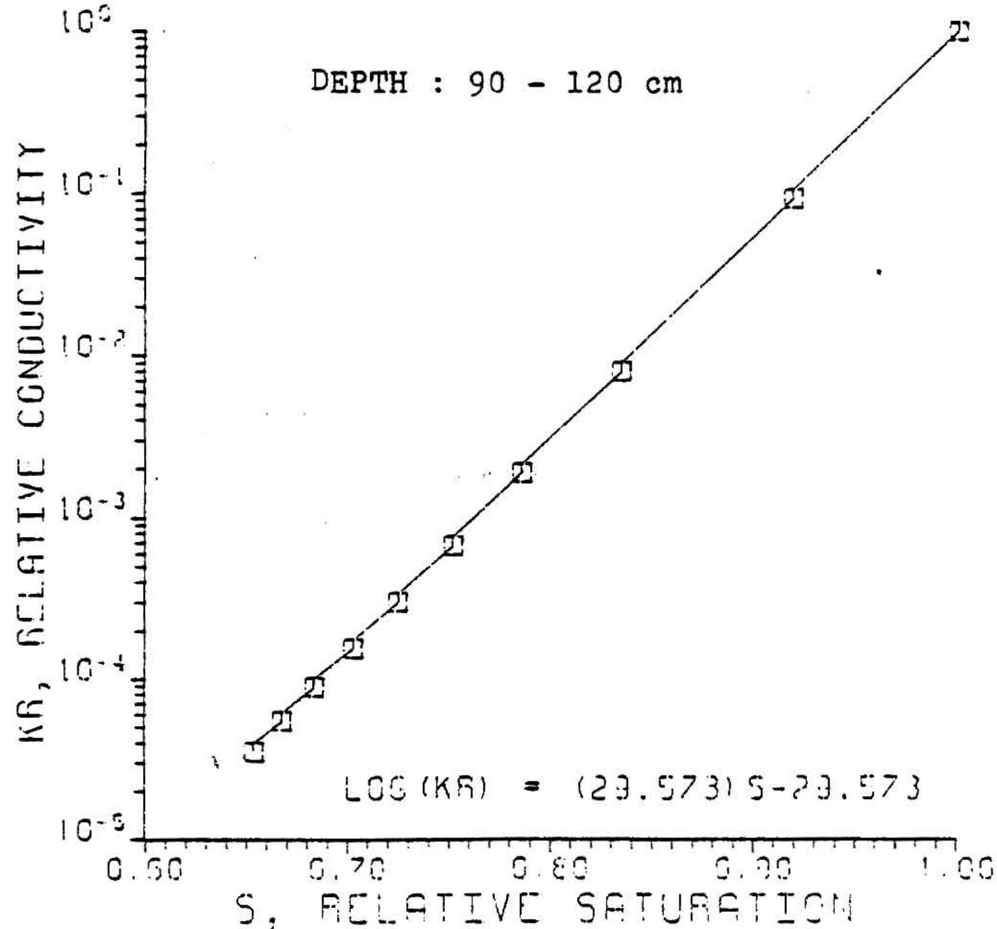
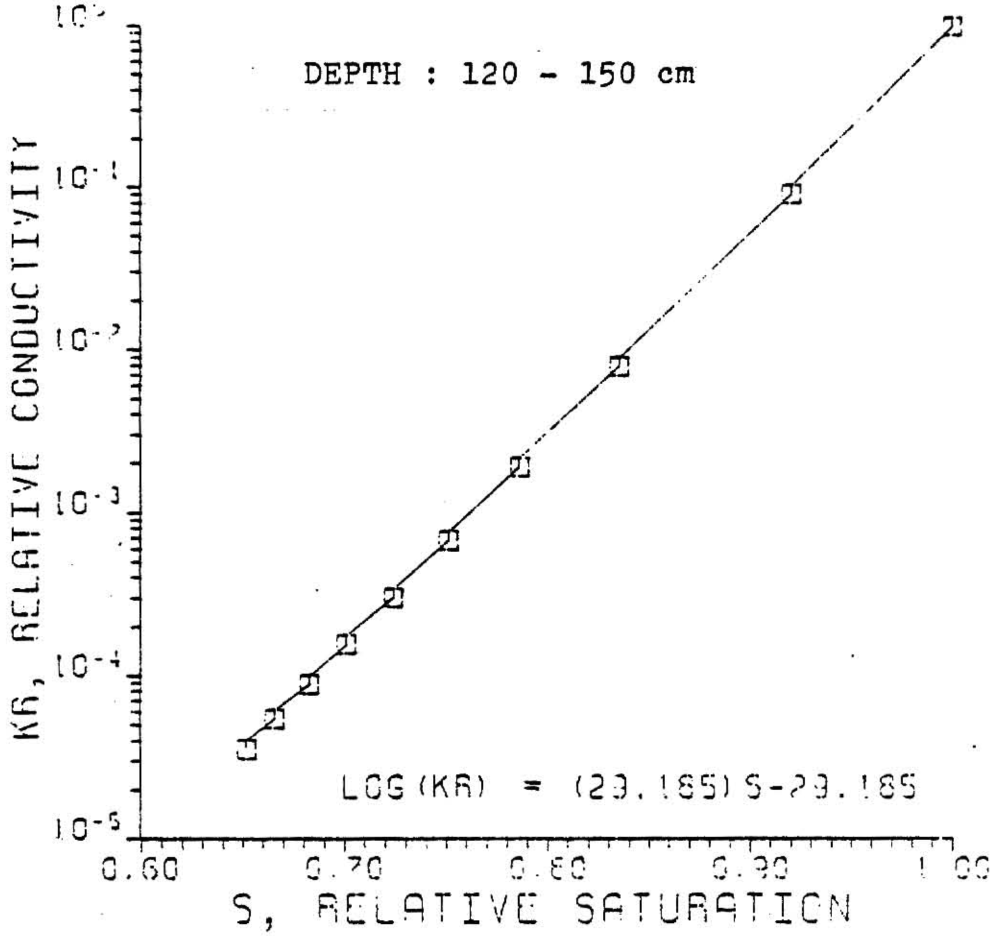


FIGURE 7. (Cont'd) Relationship of Relative Conductivity And Relative Saturation



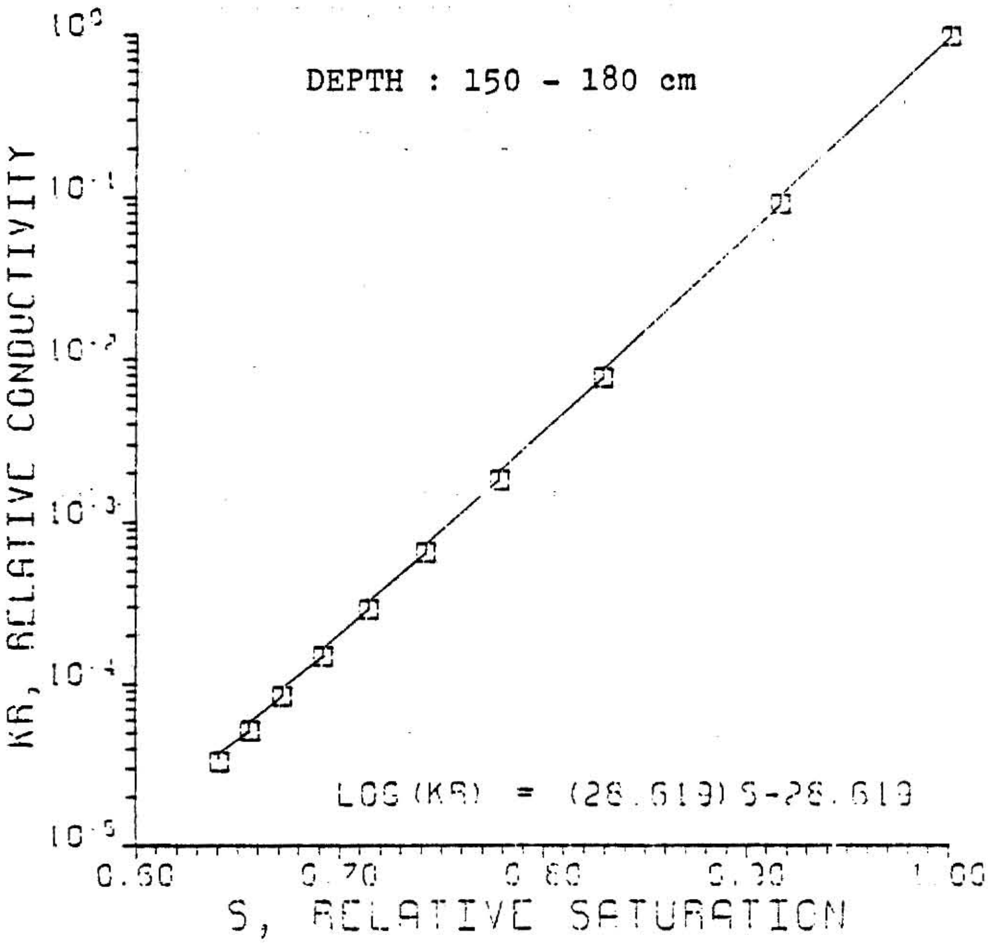
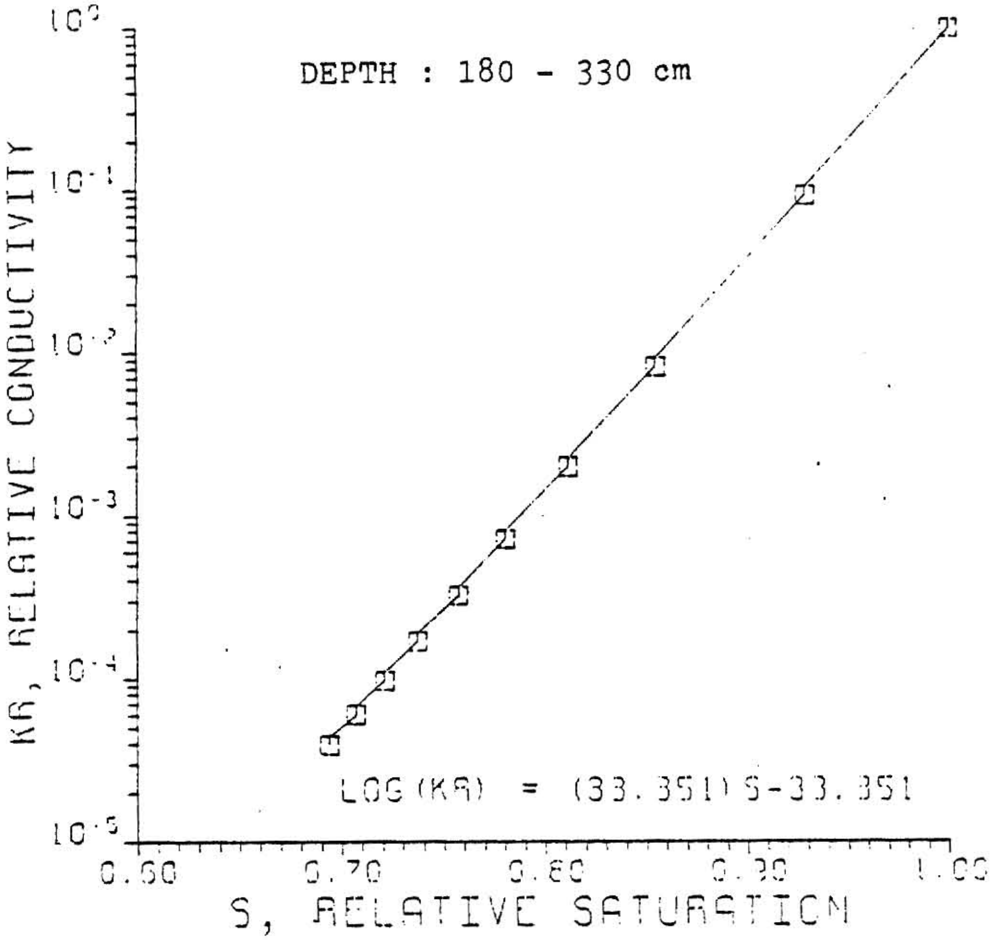


FIGURE 7. (Cont'd) Relationship of Relatove Conductivity And Relative Saturation



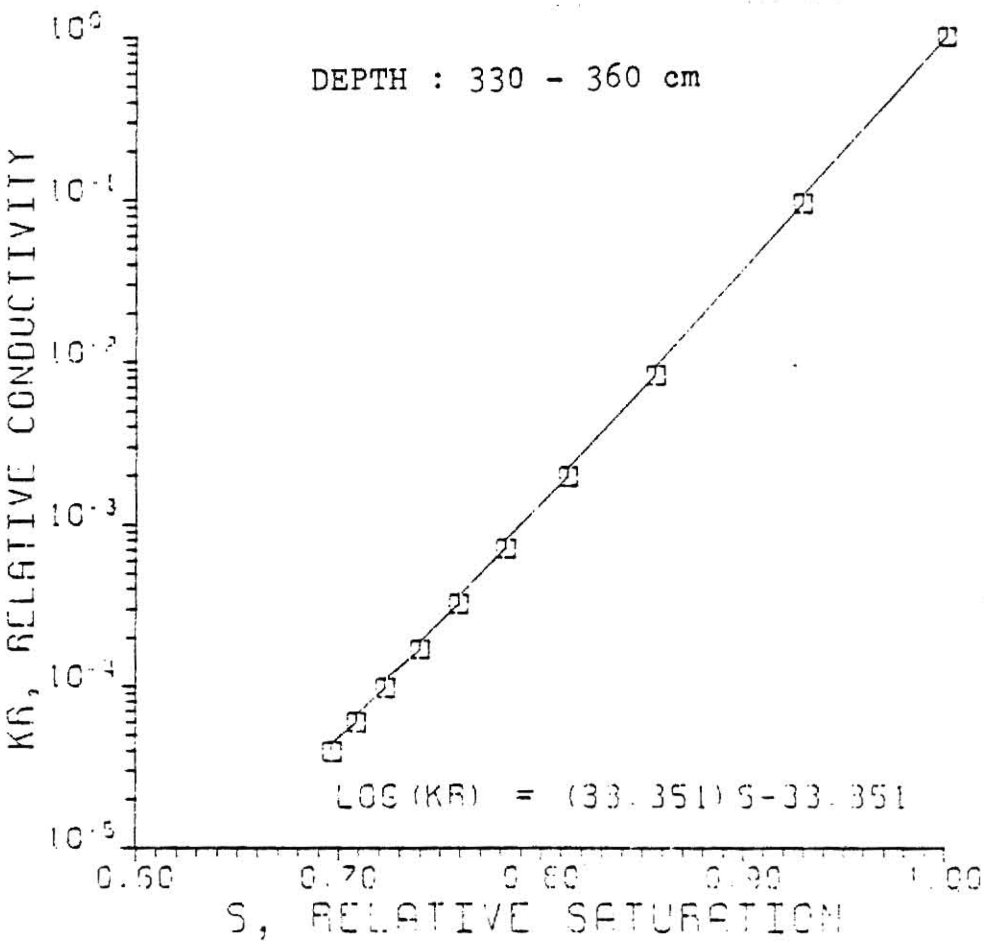
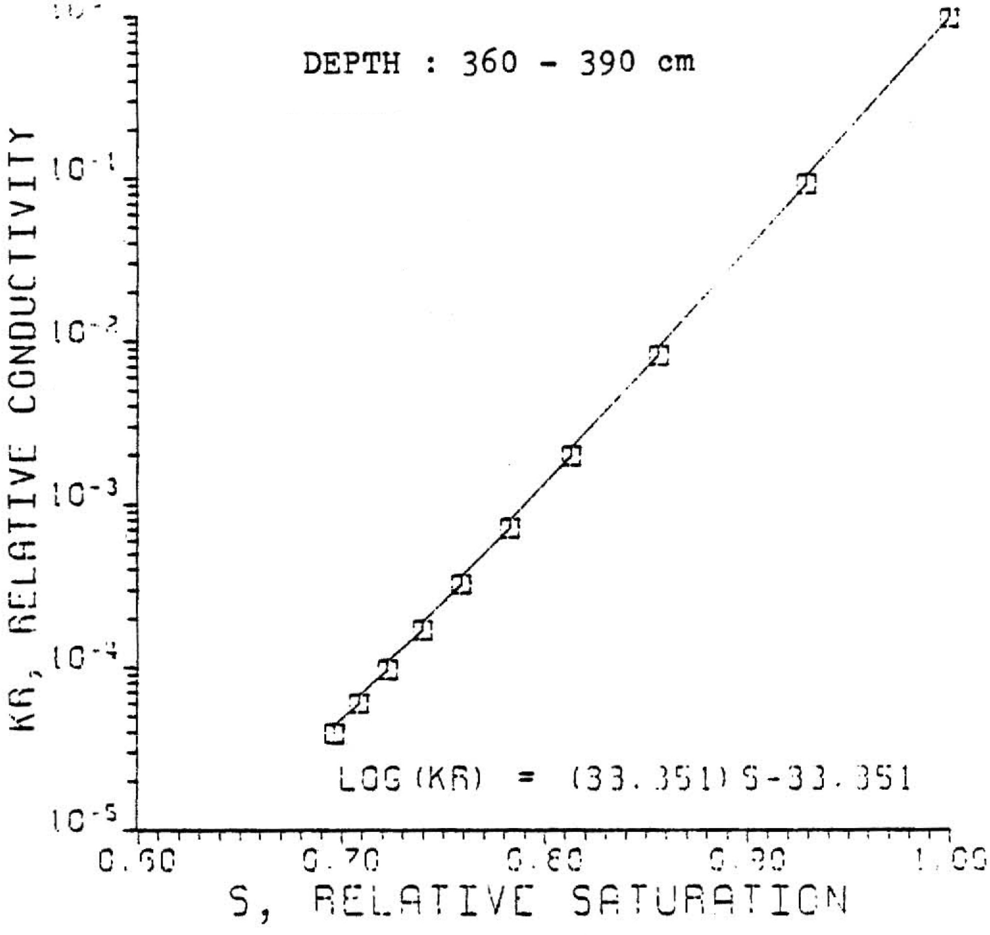


FIGURE 7. (Cont'd) Relationship of Relative Conductivity and Relative Saturation



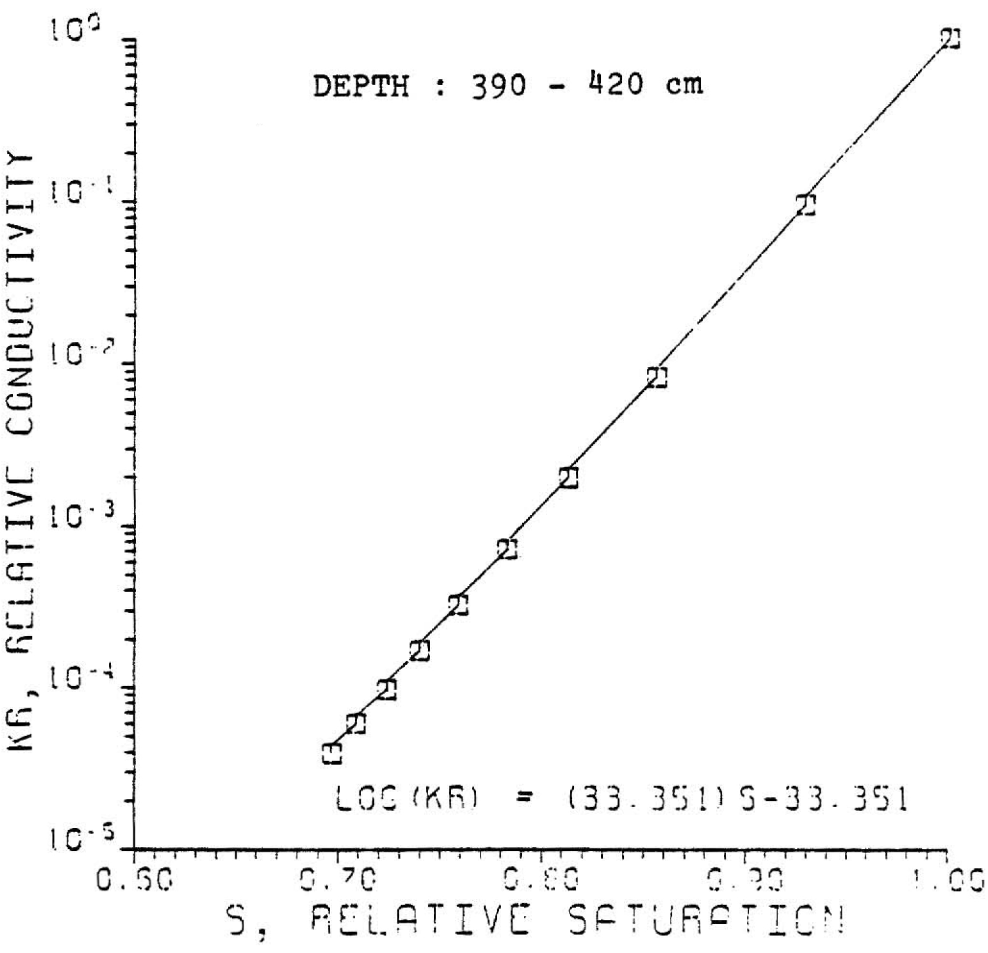


FIGURE 7. (Cont'd) Relationship of Relative Conductivity And Relative Saturation

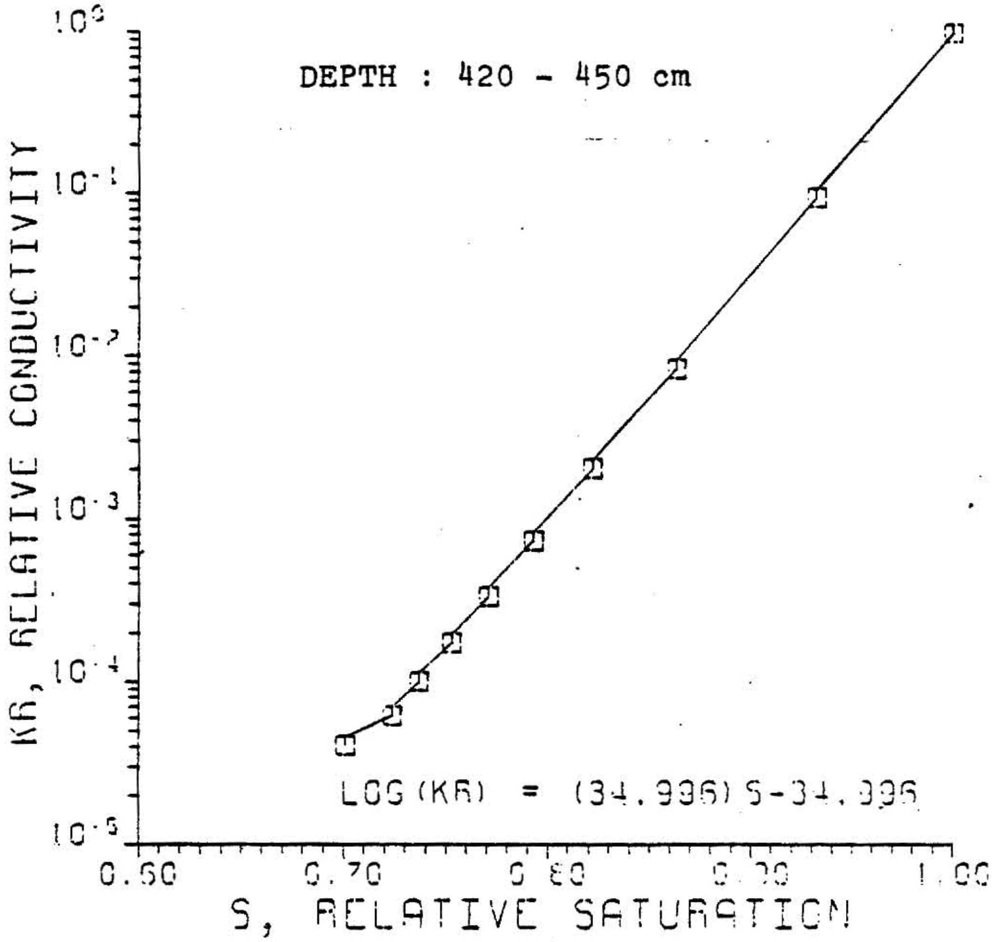


FIGURE 7. (Cont'd) Relationship of Relative Conductivity And Relative Saturation

CHAPTER 4 RESULTS ANALYSIS

The results presented in this chapter are (1) Field Data of Soil Moisture Content, (2) Model Calibration Results, (3) Fallow Efficiency Over the Experimental Period, (4) Fallow Efficiency over the Long Term, (5) Recharge Assessment Over the Experimental Period, (6) Recharge Assessment Over the Long Term

(1) Field Data of Soil Moisture Content

Neutron hydroprobe, Campbell Pacific Nuclear Model 503, was used in the field to determine the soil moisture content. Shield counts were recorded in the field. Soil moisture contents by volume were calculated by the following formula :

$$SM = 0.2854CR - 0.03834 \qquad (18)$$

where

SM = soil moisture content by volume

CR = shield count

Three blocks and six treatments were practiced in the field, but only Treatment One is studied in this research. The field data of soil moisture of treatment one is listed in Table 3. Field data of other treatments are listed in Appendix E.

(2) Model Calibration Results

Field data were used to calibrate the model and to check the model's ability to fit the field data. Figure 8 presents the calibration results and shows good agreement between the field data and values calculated by this model.

(3) Fallow Efficiency Over the Experimental Period

The measured soil moisture content to a depth of 4.5 m on August 16, 1979 was treated as the original soil moisture content. And the data on September 11, 1981 is taken for the final soil moisture content.

Original Total Soil Moisture content = 64.95 cm

Final Total Soil Moisture Content = 101.16 cm

Change In Soil Moisture Content = 36.21 cm

Total Precipitation During the Period = 104.37 cm

$$\text{Fallow Efficiency} = \frac{\text{Change in Soil Moisture}}{\text{Total Precipitation}} \times 100\%$$

$$= 34.7\ \%$$

From the short-term computer model,

Change In Soil Moisture Content = 34.97 cm

Fallow Efficiency = 33.5 %

Compared with the experimental data, only 3 percent difference between the field data and model was found. This is additional evidence that this model fits the field conditions.

(4) Fallow Efficiency Over the Long Term

Table 4 shows the fallow efficiencies over the long term (1920 to 1978). The first year (1920) was taken as wheat harvest year.

(5) Recharge Assessment Over the Experimental Period

The amount of water stored below 2.5 m (the depth from which wheat probably not remove it) was 10.4 cm (4.1 in.). For the field experiment that water was judged to be potential groundwater recharge.

(6) Recharge Assessment Over the Long term (1920 to 1978)

Soil water movement downward from 3.9 - 4.2 m layer to 4.2 - 4.5 m layer was considered as potential recharge groundwater. From the long-term model,

Total Amount of Recharge = 251.43 cm

Average Amount of Recharge = 4.26 cm/year

= 1.678 inch/year

The results of long-term runs are summarized in Appendix E. The amount of deep percolation (potential groundwater recharge) for each year during the simulation period can be found in the Summary in Appendix E.

TABLE 3. FIELD DATA : SOIL MOISTURE CONTENTS

***** DOUBLE FALLOW SOIL MOISTURE BY VOLUME *****

BLOCK	TREATMENT	DEPTH(CM)	8/16/9	11/27/9	4/ 9/0	7/ 1/0	9/17/0	12/ 4/0	1/14/1	3/16/1	5/12/1	6/15/1	7/14/1	7/28/1	9/11/1
1	1	30	0.237	0.334	0.369	0.305	0.286	0.313	0.308	0.346	0.343	0.327		0.301	0.307
2	1	30	0.215	0.336	0.358	0.318	0.350	0.340	0.329	0.337	0.352	0.348		0.338	0.336
3	1	30	0.178	0.328	0.377	0.298	0.318	0.289	0.284	0.341	0.344	0.324	0.332	0.291	0.293
AVERAGE		30	0.210	0.333	0.368	0.307	0.318	0.314	0.307	0.341	0.346	0.333		0.310	0.312
1	1	60	0.201	0.197	0.375	0.319	0.300	0.348	0.335	0.358	0.354	0.352		0.336	0.344
2	1	60	0.126	0.190	0.368	0.253	0.244	0.277	0.270	0.267	0.299	0.303		0.277	0.275
3	1	60	0.128	0.160	0.329	0.326	0.361	0.335	0.333	0.357	0.363	0.355	0.351	0.349	0.343
AVERAGE		60	0.152	0.182	0.357	0.299	0.315	0.320	0.313	0.327	0.339	0.337		0.321	0.321
1	1	90	0.155	0.155	0.341	0.317	0.315	0.342	0.323	0.332	0.352	0.339		0.328	0.333
2	1	90	0.126	0.126	0.336	0.227	0.254	0.241	0.234	0.228	0.277	0.275		0.248	0.246
3	1	90	0.128	0.128	0.296	0.260	0.296	0.275	0.279	0.290	0.310	0.311	0.276	0.293	0.235
AVERAGE		90	0.136	0.136	0.321	0.268	0.285	0.286	0.279	0.280	0.313	0.308		0.290	0.288
1	1	120	0.152	0.152	0.295	0.237	0.218	0.235	0.227	0.235	0.269	0.265		0.242	0.237
2	1	120	0.136	0.136	0.197	0.237	0.251	0.244	0.239	0.231	0.273	0.278		0.252	0.251
3	1	120	0.120	0.120	0.145	0.211	0.239	0.229	0.220	0.222	0.264	0.272	0.256	0.254	0.240
AVERAGE		120	0.136	0.136	0.212	0.228	0.236	0.236	0.229	0.229	0.269	0.272		0.249	0.243
1	1	150	0.169	0.169	0.256	0.227	0.216	0.231	0.220	0.219	0.259	0.256		0.234	0.227
2	1	150	0.150	0.150	0.160	0.199	0.223	0.220	0.200	0.198	0.228	0.249		0.228	0.221
3	1	150	0.134	0.134	0.137	0.186	0.223	0.203	0.207	0.196	0.244	0.262	0.252	0.245	0.238
AVERAGE		150	0.151	0.151	0.184	0.204	0.221	0.218	0.209	0.204	0.244	0.256		0.236	0.229
1	1	180	0.168	0.168	0.165	0.226	0.213	0.231	0.216	0.212	0.244	0.259		0.233	0.233
2	1	180	0.173	0.173	0.190	0.208	0.236	0.227	0.221	0.215	0.233	0.274		0.252	0.252
3	1	180	0.147	0.147	0.152	0.158	0.214	0.203	0.200	0.193	0.235	0.266	0.253	0.246	0.237
AVERAGE		180	0.163	0.163	0.169	0.197	0.221	0.220	0.212	0.207	0.237	0.266		0.244	0.240
1	1	210	0.176	0.176	0.170	0.208	0.204	0.224	0.208	0.203	0.229	0.254		0.229	0.229
2	1	210	0.154	0.154	0.171	0.181	0.212	0.207	0.212	0.199	0.236	0.247		0.237	0.236
3	1	210	0.168	0.168	0.173	0.145	0.207	0.209	0.209	0.203	0.237	0.276	0.264	0.263	0.255
AVERAGE		210	0.166	0.166	0.171	0.178	0.208	0.213	0.206	0.202	0.224	0.259		0.243	0.240
1	1	240	0.184	0.184	0.182	0.235	0.233	0.249	0.238	0.248	0.262	0.283		0.267	0.267
2	1	240	0.145	0.145	0.153	0.141	0.194	0.196	0.182	0.182	0.187	0.225		0.224	0.221
3	1	240	0.167	0.167	0.175	0.160	0.207	0.216	0.213	0.212	0.224	0.281	0.231	0.272	0.264
AVERAGE		240	0.165	0.165	0.170	0.179	0.211	0.220	0.211	0.214	0.224	0.263		0.254	0.251
1	1	270	0.186	0.186	0.185	0.203	0.212	0.237	0.225	0.215	0.237	0.265		0.249	0.240
2	1	270	0.140	0.140	0.146	0.105	0.171	0.179	0.175	0.173	0.174	0.203		0.211	0.211
3	1	270	0.165	0.165	0.172	0.150	0.180	0.186	0.200	0.194	0.196	0.254	0.260	0.253	0.254
AVERAGE		270	0.164	0.164	0.168	0.153	0.188	0.200	0.200	0.194	0.202	0.241		0.238	0.236
1	1	300	0.177	0.177	0.175	0.194	0.207	0.218	0.224	0.222	0.215	0.256		0.247	0.250
2	1	300	0.128	0.128	0.135	0.096	0.133	0.157	0.164	0.160	0.161	0.180		0.208	0.210
3	1	300	0.154	0.154	0.156	0.140	0.166	0.168	0.173	0.166	0.175	0.207	0.235	0.237	0.236
AVERAGE		300	0.153	0.153	0.155	0.143	0.169	0.188	0.187	0.183	0.185	0.214		0.231	0.232
1	1	330	0.170	0.170	0.166	0.167	0.194	0.222	0.211	0.210	0.210	0.239		0.235	0.235
2	1	330	0.112	0.112	0.116	0.084	0.107	0.129	0.124	0.137	0.144	0.152		0.192	0.197
3	1	330	0.153	0.153	0.164	0.136	0.161	0.163	0.164	0.163	0.175	0.178	0.224	0.229	0.231
AVERAGE		330	0.145	0.145	0.149	0.129	0.154	0.171	0.166	0.170	0.176	0.190		0.219	0.221
1	1	360	0.177	0.177	0.170	0.145	0.176	0.218	0.197	0.198	0.197	0.214		0.228	0.229
2	1	360	0.110	0.110	0.114	0.134	0.103	0.116	0.114	0.101	0.112	0.118		0.180	0.175
3	1	360	0.152	0.152	0.155	0.138	0.165	0.158	0.154	0.168	0.166	0.167	0.194	0.212	0.202
AVERAGE		360	0.146	0.146	0.146	0.122	0.148	0.157	0.155	0.156	0.158	0.166		0.200	0.215
1	1	390	0.173	0.173	0.170	0.164	0.157	0.231	0.220	0.223	0.225	0.227		0.238	0.250
2	1	390	0.108	0.108	0.110	0.084	0.102	0.101	0.097	0.097	0.101	0.101		0.101	0.151
3	1	390	0.135	0.135	0.144	0.132	0.154	0.142	0.142	0.152	0.147	0.150	0.155	0.162	0.204
AVERAGE		390	0.139	0.139	0.141	0.127	0.143	0.158	0.153	0.157	0.158	0.159		0.174	0.204
1	1	420	0.174	0.174	0.173	0.160	0.167	0.222	0.218	0.220	0.214	0.222		0.246	0.257
2	1	420	0.111	0.111	0.103	0.087	0.105	0.103	0.105	0.095	0.098	0.099		0.099	0.105
3	1	420	0.131	0.131	0.138	0.122	0.145	0.136	0.143	0.139	0.139	0.144	0.146	0.142	0.164
AVERAGE		420	0.139	0.139	0.138	0.123	0.139	0.154	0.154	0.151	0.150	0.155		0.162	0.175
1	1	450	0.159	0.159	0.163	0.163	0.157	0.221	0.221	0.227	0.222	0.225		0.262	0.273
2	1	450	0.119	0.119	0.108	0.100	0.116	0.118	0.113	0.114	0.118	0.115		0.107	0.113
3	1	450	0.128	0.128	0.134	0.109	0.132	0.131	0.128	0.126	0.123	0.130	0.127	0.130	0.127
AVERAGE		450	0.135	0.135	0.135	0.124	0.135	0.157	0.154	0.156	0.151	0.137		0.166	0.171

TABLE 4 LONG-TERM FALLOW EFFICIENCY
(FROM 1920 TO 1978)

FALLOW PERIOD	PRECIPITATION (in cm)	CHANGE IN SM (in cm)	FALLOW EFFICIENCY (in percent)
JULY 1920 - SEP. 1922	116.12	43.48	37.75
JULY 1923 - SEP. 1925	94.49	30.59	32.37
JULY 1926 - SEP. 1928	106.89	38.61	36.12
JULY 1929 - SEP. 1931	118.73	48.09	40.50
JULY 1932 - SEP. 1934	69.93	19.91	28.47
JULY 1935 - SEP. 1937	71.23	18.55	26.04
JULY 1938 - SEP. 1940	75.50	20.91	27.70
JULY 1941 - SEP. 1943	99.91	34.05	34.08
JULY 1944 - SEP. 1946	103.56	40.32	38.93
JULY 1947 - SEP. 1949	124.25	43.98	35.40
JULY 1950 - SEP. 1952	103.40	37.09	35.87
JULY 1953 - SEP. 1955	81.42	23.94	29.40
JULY 1956 - SEP. 1958	132.84	52.38	39.43
JULY 1959 - SEP. 1961	115.18	44.18	38.36
JULY 1962 - SEP. 1964	87.50	29.79	34.05
JULY 1965 - SEP. 1967	89.00	32.28	36.27
JULY 1968 - SEP. 1970	100.28	31.43	31.34
JULY 1971 - SEP. 1973	103.87	37.82	36.41
JULY 1974 - SEP. 1976	92.58	34.22	36.96
JULY 1977 - DEC. 1978[1]	55.44	21.43	38.65
TOTAL	1942.12	683.32	35.18

[1] incomplete cycle

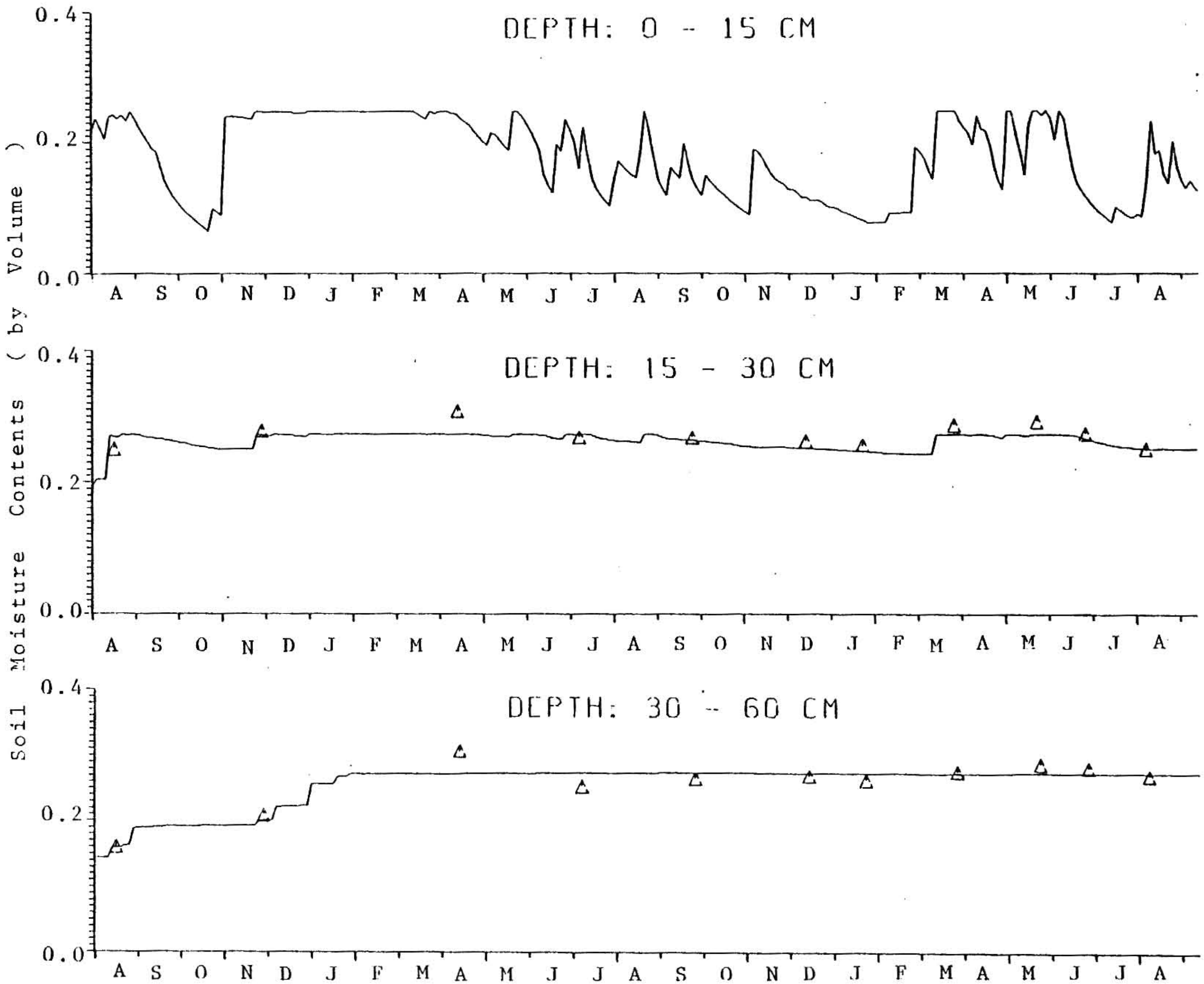


FIGURE 8. Model Calibration Results

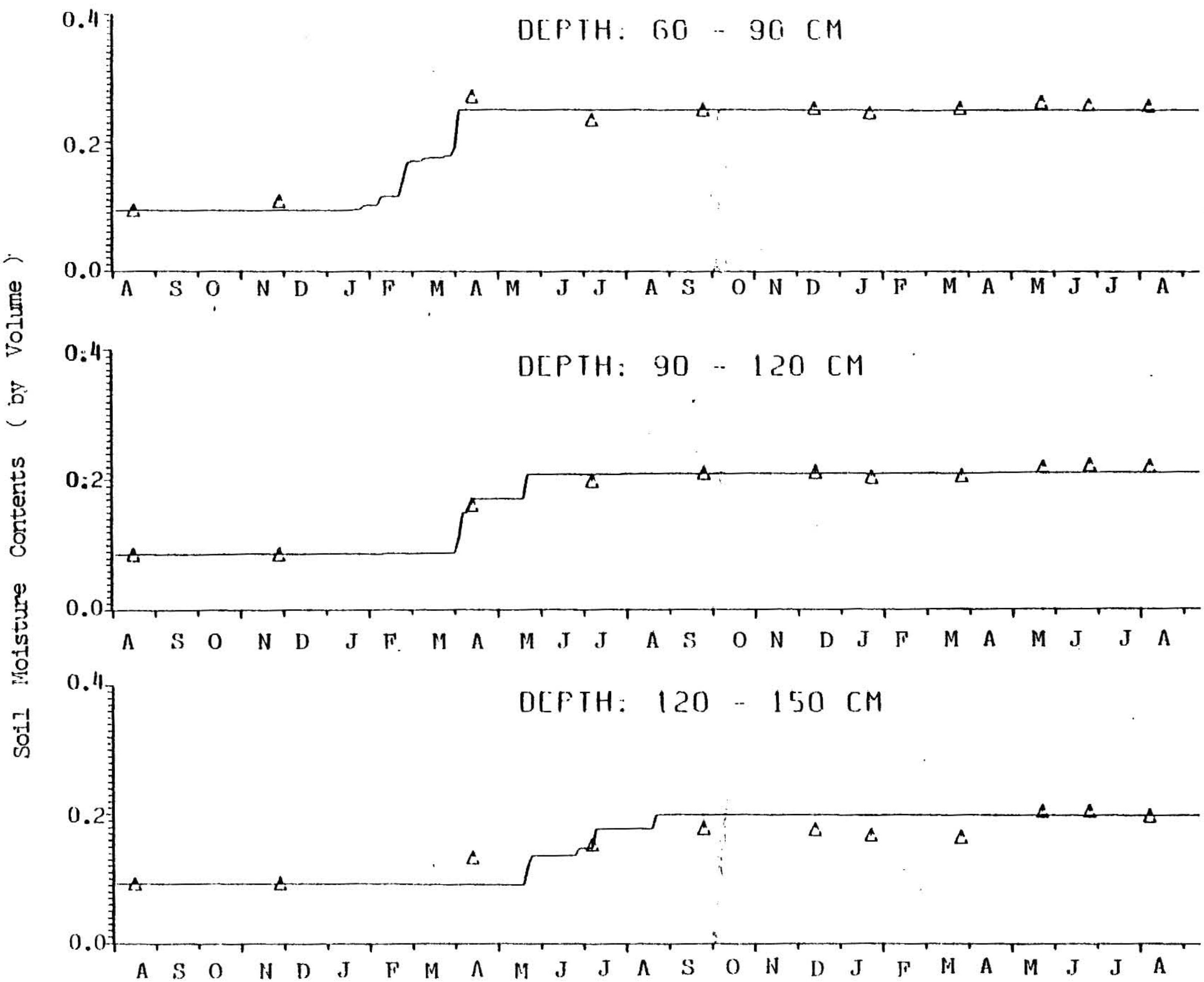
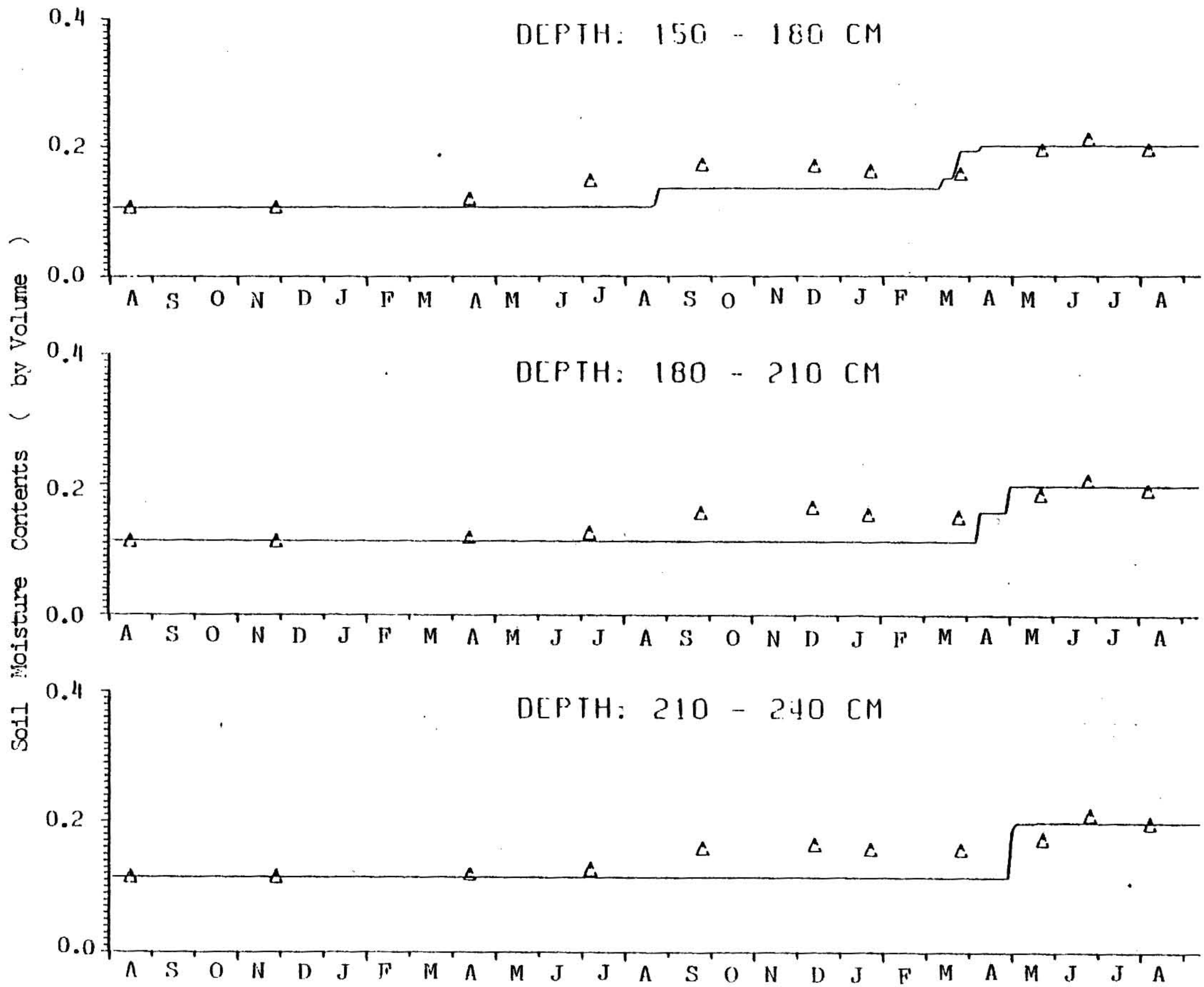


FIGURE 8. (cont'd)



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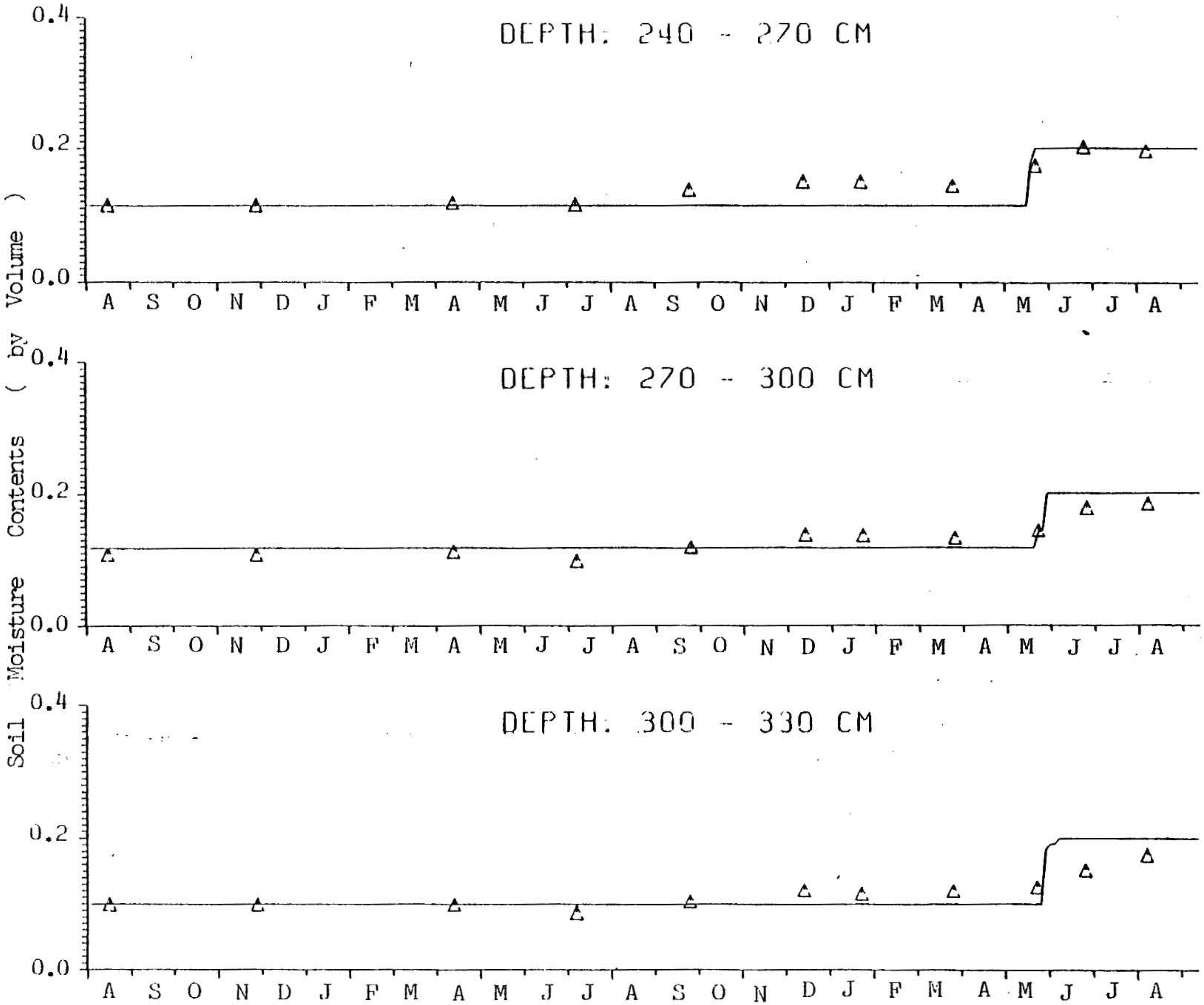

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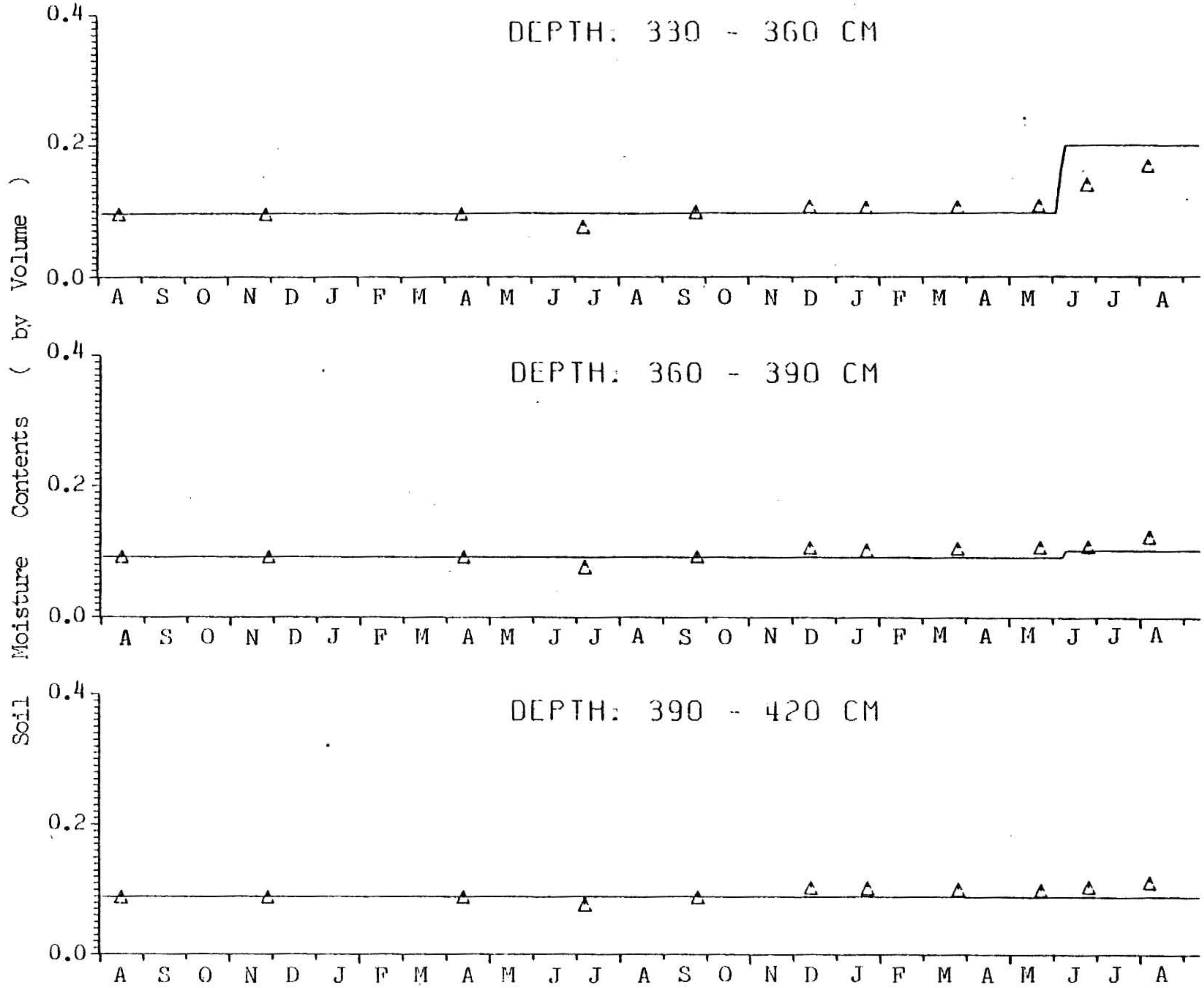

FIGURE 8. (cont'd)

CHAPTER 5 CONCLUSIONS ANI RECOMMENIATION

Conclusions

The major purpose of this research was to verify that the practice of double fallow could greatly increase the groundwater recharge potential. This purpose was achieved by conducting a field experiment, calibrating a short-term water budget model with the field experiment, and running a long-term continuous water budget model. From the results of field experiments, 34.7 percent fallow efficiency was measured, i.e. 34.7 percent of precipitation during the experimental fallow period was stored in the soil layers. Comparing it with 30 percent fallow efficiency (typical value for wheat-fallow) about 16 percent better storage efficiency over a 27-month period was obtained when compared to conventional fa Much of this improvement is attributed to no-tillage. Most of all, the results of the experiment showed that soil water did move down to 4.5 m which is far below the rooting zone for wheat, and such water could become potential recharge if the practice were continued. The long-term model showed an average 35 percent fallow efficiency and an average of 4.3 cm (1.7 in.). of potential recharge per year. The amount of recharge, 4.3 cm per year, might not appear to be very much. (Almost no potential rcharges occurs under cropped fields that receive only the precipitation that falls on them.) Emphasis must stress here, however, over a long term, for instance, 50 years, which is a long period for a man's life but only a spot in the earth's history from the geological point of view, the amount would be significant. Also, wheat-fallow is extensively practiced in western Kansas. There's a large area over which recharge could be increased. For instance, an average potential recharge of 4.3 cm/year under one million ha (2.47 million acres) would equal 349,917 ac-ft/year. So, the conclusion drawn from this research : for better protection of groundwater resources in western Kansas, wheat-double fallow is one of the feasible methods and should be favorably considered.

Recommendations

In relation to further research, the following recommendations are made:

1. The field experiment should be continued for at least 10 more months. Wheat should be planted on those plots which were practicing double fallow. By doing this, some evidence the effect of double fallow on wheat yield and the depth to which wheat roots will remove water could be obtained. Several cycles should be evaluated to provide more confidence in the results of the whole concept.
2. In this study, chemical mulch (no-till, 8k) is the fallowing practice used. In fact, many other improved practices may be applied during the fallow period, such as chieseling, etc. It could be valuable to evaluate the effect of different fallowing practices to determine which one would be the optimum for potential recharge. Also,

it would be valuable to study several cycles closely to better develop the computer model to simulate these effects.

3. A further part related to the subject of wheat-double fallow should be an economic analysis. The gross crop yields do not mean the same benefit to the farmers. Many economic factors must be considered, such as the probable crop price variation during the fallow period, the extra expenditure needed, for instance, larger storage may be needed for the larger amount of yield in a single year, tax rate, interest rate, labor etc.. This study is out of the scope of water resources, but it might be the very part which farmers would be most concerned.

REFERENCES

Anderson, C. E. 1975 A water balance model for agricultural watersheds on deep loess soils. Unpublished Ph.D. Thesis. Kansas State University Library, Manhattan, Kansas.

Anschutz, J. A., J. K. Koelliker, J. J. Zovne, T. A. Bean and W. H. Neibling. 1976. Continuous watershed modeling of wastewater storage and land application to improve design parameters. Proc. of the 8th Annual Waste Management Conference, pp. 228-241. Cornell University, Ithaca, New York.

Baier, W. and G. W. Robertson. 1966. A new versatile soil moisture budget. Can. Jour. Plant Sci. 46:299-315.

Bean, T. A. 1976. A continuous watershed model for evaluation and design of feedlot runoff control systems. Unpublished M.S. Thesis. Kansas State University Library, Manhattan, Kansas.

Bond, J, J, and W. O. Willis, 1969. Soil water evaporation: surface residue rate and placement effect. Soil Sci. Soc. Amer. Proc. 33:445-448.

Bond, J. J. and W. O. Willis. 1970. Soil water evaporation: first stage drying as influenced by surface residue and evaporation potential. Soil Sci. Soc. Amer. Proc. 34:924-928.

Bouwer, H., and R. D. Jackson, 1974. Determining soil properties. In: Drainage for agriculture, Jan van Schilfgaarde (ed.). Agronomy 17:611-672, Am. Soc. of Agron., Madison, Wis.

Bouwer, H., 1978. Groundwater Hydrology, McGraw-Hill Book Company, New York, N. Y.

D'Hollander, E. H. 1979. Estimation of the pore size distribution from the moisture characteristic. Water Resources Research, Vol. 15, No. 1.

Doering, E. J. 1965. Soil-water difsivity by the one-step method. Soil Science 99:322-326.

Gray, D. M. 1973. Principles of Hydrology, Water Information Center, Inc.

Greb, B. W., D. E. Smika, N. P. Woodruff, and C. J. Whitfield. 1974. Summer fallow in the central Great Plains. In: Summer Fallow in the Western United States, pp. 51-85. Conservation Research Report No. 17. USDA, Agricultural Research Service, Washington, D. C.

Iraelsen, O. W. and Hansen, V. E., 1962. Irrigation Principles and Practices, 3rd ed., John Wiley and Sons, Inc., New York, N.Y.

Kanemasu, E. T. 1975. Application of information on water-soil-plant relations for use and conservation of water. Kansas Contributing Project Report Western 67 (revised). Twin Falls, Idaho. Evapotranspiration Laboratory, Kansas State University, Manhattan, Kansas.

Koelliker, J. K., F. E. Ohmes, and W. H. Neibling. 1976. Land forming systems to improve water use efficiency. Contribution 184. Kansas Water Resources Research Institute. Manhattan, Kansas.

Linsley, R. K., M. A. Kohler, and J. L. H. Paulhus, 1975. Hydrology for Engineers, 2nd ed., McGraw-Hill, Inc., New York, N. Y.

Neibling, W. H. 1976. Estimating groundwater recharge from conservation bench terraces. Unpublished M. S. Thesis. Kansas State University Library, Manhattan, Kansas.

Penman, H. L. 1948. Natural Evaporation From Open Water, Bare Soil and Grass. Proceedings of the Royal Society of London, Series A, Vol. 193, pp. 120-145.

Ritchie, J. T. 1972. Model for predicting evaporation from row crop with incomplete cover. Water Resources Research 8:1204-1213.

Saxton, K. E., H. P. Johnson and R. H. Shaw. 1974. Modeling evapotranspiration and soil moisture. Trans. of the ASAE 17:673-677.

Shih, S. F., L. H. Allen Jr., I.C. Hammond, J. W. Jones, J. S. Rogers, A. G. Smajstrla, 1981. Comparison of methods of evapotranspiration estimation, ASAE Paper No. 81-2015. For presentation at the 1981 Summer Meeting, ASAE.

Sinclair, L. R., D. W. Fitzsimmons, and G. L. Bloomsburg, 1974. Permeability of saturated field soils calculated from laboratory desaturation data, Trans. ASAE, Vol 17, No. 3.

Sinclair, L. R., 1981. Improved conductivities from desorption data. ASAE Paper No. 81-2027. Presented at the 1981 Summer Meeting, ASAE, Orlando, Florida.

Smika, D. E. and G. A. Wicks. 1968. Soil water storage during fallow in the central Great Plains as influenced by tillage and herbicide treatments. Soil Science Society of America Proceedings 32:591-595.

United States Department of Agriculture, Soil Conservation Service, Engineering Division. 1967. Irrigation water requirements. Technical Release No. 21, 83 p.

United States Department of Agriculture, Soil Conservation Service. 1972. Hydrology, National Engineering Handbook, section 4, Washington, D. C.

Ward, R. C. 1975. 'Interception', p. 54-70. Principles of Hydrology. 2nd ed. McGraw-Hill, Inc., New York, N. Y.

Zovne, J. J. and A. Nawaz. 1975. Predicting evapotranspiration from agricultural watersheds under dry conditions. Contributions No. 164, Kansas Water Resources Research Institute, Manhattann, Kansas.

Zovne, J. J. and J. K. Koelliker, 1979. Application of continuous watershed modeling to feedlot runoff management and control. Publication No. EPA-600/2-79-065, Robert S. Kerr Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Ada, Oklahoma.

APPENDIX A-I

THEORY AND PROCEDURE OF IMPROVED CONDUCTIVITY FROM DESORPTION DATA

THEORY

(Adapted From Sinclair, 1981)

The equation used to calculate unsaturated hydraulic conductivity from desorption data will be derived by equating Poiseuille's law with Darcy's law. If Poiseuille's law is applied to a tube of general geometry, the solution is :

$$u = -\ (L^2/a)\nabla P \qquad \text{(A1)}$$

where

u = average velocity in the tube,

L = some characteristic length in the tube,

a = a constant which depends on the viscosity of water, the choice of the characteristic length L, and the geometry of the pore,

∇P = the pressure gradient causing flow within the tube.

Darcy's law is commonly written

$$q = -K\nabla P \qquad \text{(A2)}$$

where

q = the specific discharge rate (the volume of water flowing through a cross-sectional area of soil per unit time),

K = Hydraulic conductivity

∇P = is again the pressure gradient.

Although q and u both have the units of velocity, they cannot be equated since one is the apparent velocity of water discharging from the cross sectional area of a soil and the other is the velocity of water within a flow tube in the soil. Figure A1 shows a diagram of a hypothetical cube of soil with water flowing from left to right. If a volume of water, V, flows through the cube and out of the right face of the cube in time, t then the Darcy velocity, q, is

$$q = (V/T) / l^2 = Q/A \qquad (A3)$$

where, A, is the cross sectional area of the right hand face. Whereas, the average velocity in a flow tube, u, is the length of the flow tube, lu, divided by the time it takes for water to travel across the soil cube, tu, or

$$u = lu/tu \qquad (A4)$$

Now, lets assume that there is only one pore discharging from the right hand face in Figure A1 for time tu and has a cross sectional area of Aw. Then the volume of water discharged is

$$Vw = lu \times Aw$$

$$Q = Vw/tu = lu \times Aw / tu \qquad (A5)$$

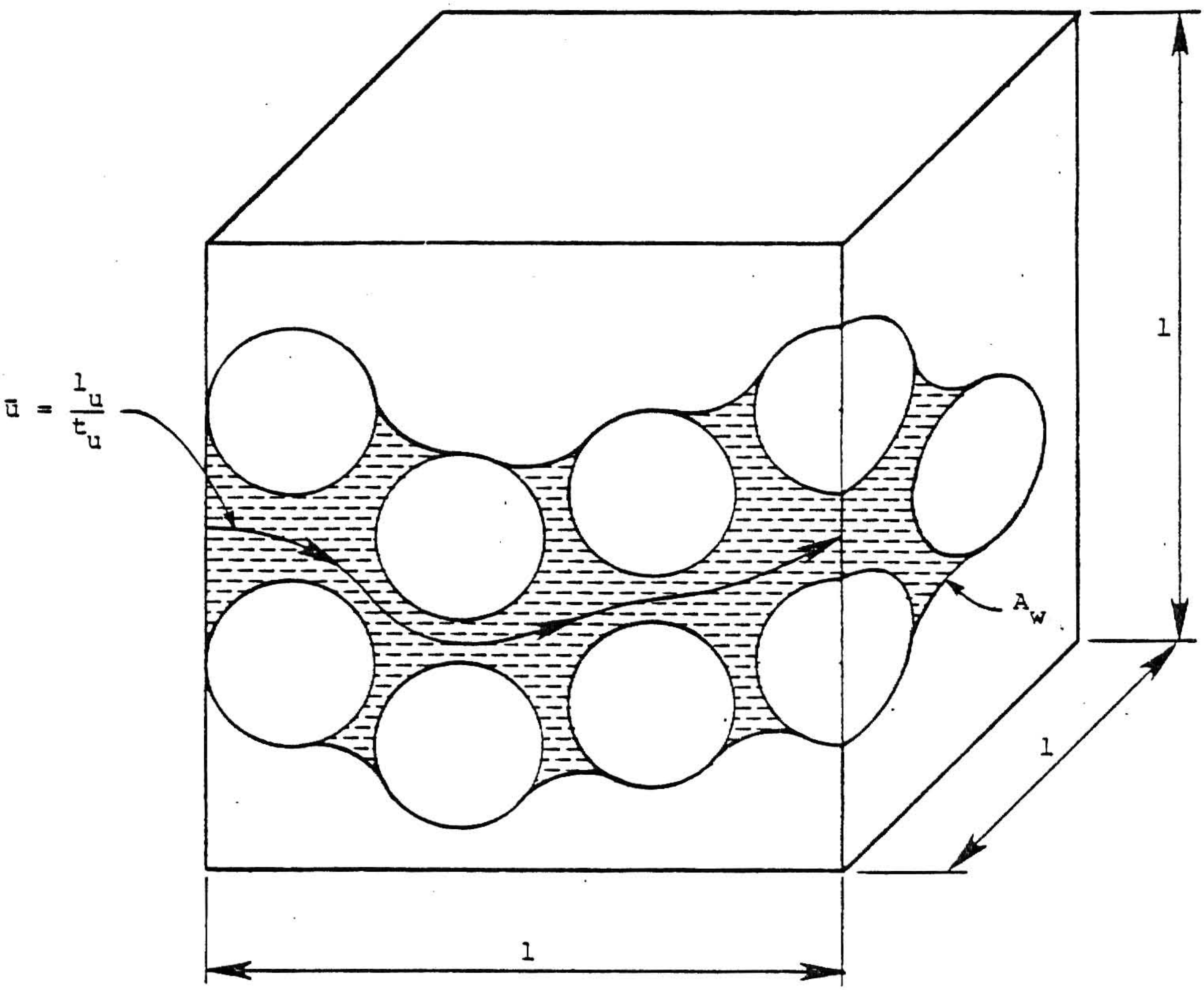

FIGURE A1. Schematic Diagram of A Flow Tube Through A Volume of Soil

Substituting Equation A4 into Equation A5 for lu gives

$$Q = u \times Aw \quad (A6)$$

and substituting Equation A6 into Equation A3 gives

$$q = u \times Aw / l^2 \quad (A7)$$

Multiplying by l/l and lu/lu gives

$$q = (u \times Aw \times lu \times l) / (l^3 \times lu) \quad (A8)$$

and noting that $l^3 = V$, $Aw \times lu$ = the volume of water (Vw) in the cube, and that multiplying porosity, $\emptyset$, (= V/Vv) times saturation (S = Vw/Vv) gives Vw/V, we have

$$q = u \times \emptyset \times S \times l/lu \quad (A9)$$

Substituting Equations A1 and A2 into Equation A9 gives

$$- K \nabla P = - (L^2/a) \times \emptyset \times S \times (l/lu) \times \nabla P$$

Cancelling ∇P from both sides of the two equations and defining tortuosity T as lu/l we have

$$K = (L^2 \times S \times \emptyset) / (a \times T) \quad (A10)$$

Burdine (1953) found that the tortuosity varies with saturation, S,

$$T = Tl/Se^2 \quad (A11)$$

where

$Se = (S - Sr) / (1 - Sr)$, effective saturation

Sr = residual saturation

Tl = tortuosity at saturation, which is constant for a given soil.

Substituting Equation A11 into A10 and defining a new constant

$D = a \times Tl / \phi$ gives

$$K = (L^2 \times S \times Se^2) / D \quad (A12)$$

For a bundle of tubes with different sizes and geometry, the value L^2 should be replaced with the average value of L^2 or, using probability terms, the expected value of L^2, $(E(L^2))$, sometimes denoted $\langle L^2 \rangle$.

DETERMINATIN OF $\langle L^2 \rangle$

The derivation of Equation A12 was general so that the choice of the characteristic length L can be somewhat arbitrary. It is convenient to set L equal to the radius of curvature (R) across the air water interface within the soil since this can be related to the suction in the soil, P, by

$$R = 2 \times \sigma \times Cos(A) / Pc \quad (A13)$$

where

σ = surface tension of water (72.7 dynes/cm², 20°C)

A = contact angle between water and soil,

Pc = P/(d x g)

d = density of water (1 gm/cm³)

g = acceleration of gravity (981 cm/sec²)

P = suction in soil in $dynes/cm^2$

Probability theory states that the expected value of R^2 can be determined from

$$\langle R^2 \rangle n = \int_{Ra}^{Rn} R^2 F(R)\, dR \qquad (A14)$$

as long as F(R) is a probability density function over the interval $Ra < R < Rb$. F(R) is defined as a probability density function if F(R) is integrable, non-negative and

$$\int_{Ra}^{Rb} F(R)\, dR = 1$$

Such a function can be constructed from a desorption curve for a soil. It can be shown that the number of pores N of radius R which desaturate to cause a change in saturation, dS, is

$$N = (C/R^2)\ [(dS/d(1/Pc)] \qquad (A15)$$

where the constant C depends on the pore geometry, the surface tension of water (σ), and the contact angle (A).

Since flow is governed by the pores that contain water, we are interested in the number of pores which contain water rather than the number of pores of a given radius (D'Hollander, 1979). We therefore choose a function which reflects the number of pores containing water or

$$F(R) = \sum N = \sum (C/R^2)[dS/d(1/Pc)] \qquad (A16)$$

Equation A16 defines a cummulative pore size distribution function for a soil.

This function will be a probability density function if we divide it by the area under the curve over the interval of R. Then,

$$\langle R^2 \rangle = \int_{Ra}^{Rn} [R^2 F(R) / \int_{Ra}^{Rb} F(R)\,dR]\,dR \tag{A17}$$

and,

$$\int_{Ra}^{Rn} [F(R) / \int_{Ra}^{Rb} F(R)\,dR]\,dR = 1$$

Note that the constant C in Equation A16 can come outside the integral in Equation A17 and cancels. Therefore, Eq uation A17 holds for any pore geometry within a soil. It should be noted that the constant D in Equation A12 has not been evaluated. Since it would be very difficult to determine this constant, the use of Equation A12 must be restricted in practice to determining relative permeabilities (Kr) where

$$Kr = K \times D / (Ks \times D) \tag{A18}$$

where

Ks = Saturated conductivity

K = Unsaturated conductivity calculated from equation A12

D = Constant

Notice that the constant D now cancels in Equation A18.

LITERATURE CITED

Bouwer, H. and R. D. Jackson, 1974. Determining soil properties. In: Drainage for agriculture, Jan van Schilfgaarde (ed.) Agronomy 17:611-672, Am. Soc. of Agron., Madison, Wis.

Burdine, N. T., 1953. Relative permeability calculations from pore size distribution data, Petro. Trans., Amer. Inst. Mining Metal Eng. 198:71-78.

D'Hollander, E. H., Feb. 1979. Estimation of the pore size distribution from the moisture characteristic, Water Resources Research, Vol.1, No. 3.

Sinclair, L. R., D. W. Fitzsimmons, and G. L. Bloomsburg, 1974. Permeability of saturated field soils calculated from laboratory desaturation data, Trans. ASAE, Vol. 17, No. 3.

PROCEDURE

The procedure for applying this method to calculate unsaturated K for each soil layer follows. A computer program have been designed to carry out following steps. And Table A1 is a sample output of this program.

1. A regressional curve is derived through the desorption data as shown in Figure 6. (Chapter 3, p. 30)
2. Small intervals are chosen along the curve and the value of soil tension (P) and relative saturation (S) are tabulated as shown in Table A1.
3. Starting at the highest P, calculating the radius of the air water interface (R) using Equation A13. (Column 3 in Table A1)
4. Calculate the average radius for each interval. (As shown in Column 4 in Table A1)
5. Calculate the number of pores for each interval using Equation A15. C can be any value since it will be cancelled later. This is shown in Column 5 in Table A1.
6. Calculate probability density function F(R) by accumulating the number of pores as shown in Column 6 Table A1.
7. Multiply F (Column 3) by F(R) (Column 6) as shown in Column 7.
8. Determine the area under each increment of the curve determined by $R^2F(R)$ vs R. Use trapazoidal formula on Column 3 and 7 of Table A1 as shown in Column 8.
9. Acculumate the values in Column 8 of Table A1 as shown in Column 9. This is the area under the curve $R^2F(R)$ vs R.

10. Use trapozoidal formula on Column 3 and 6 of Table A1 to determine the area under the curve F(R) vs R.
11. Divide each value in Column 9 by the area under F(R) (step 10) to determine the value of <R^2> shown in Column 10 in Table A1.
12. Calculate relative conductivity (KR) using Equation A12 and A18. Ks x D in Equation A18 is calculated using the last value in Column 10.

A FORTRAN program was designed to carry out the above procedure. The required input information for each soil layer includes : the slope and intercept of the regressional curve derived through the desorption data, saturation soil moisture content and residual saturation.

The program is listed in Appendix A-II. Figure 7 (Chapter 3, P. 36) shows the results from this program.

CALCULATION OF HYDRAULIC CONDUCTIVITY FROM DESORPTION DATA

1	2	3	4	5	6	7	8	9	10	11
PC	S	R	RBAR	N	FR	R2FR	DR2FR	SUMC	L2	KR
15300.	0.210	0.969E-05	0.000E 00	0.000E 00	0.000E 00	0.000E 00	0.000E 00	0.000E 00	0.000E 00	0.000E 00
14280.	0.217	0.104E-04	0.100E-04	0.159E 14	0.159E 14	0.171E 04	0.591E-03	0.591E-03	0.000E 00	0.000E 00
13260.	0.225	0.112E-04	0.108E-04	0.128E 14	0.287E 14	0.358E 04	0.211E-02	0.270E-02	0.000E 00	0.000E 00
12240.	0.234	0.121E-04	0.116E-04	0.102E 14	0.389E 14	0.569E 04	0.432E-02	0.702E-02	0.000E 00	0.000E 00
11220.	0.243	0.132E-04	0.127E-04	0.790E 13	0.467E 14	0.815E 04	0.762E-02	0.146E-01	0.000E 00	0.000E 00
10200.	0.253	0.145E-04	0.139E-04	0.601E 13	0.527E 14	0.111E 05	0.127E-01	0.274E-01	0.000E 00	0.000E 00
9180.	0.265	0.161E-04	0.153E-04	0.444E 13	0.572E 14	0.149E 05	0.210E-01	0.484E-01	0.000E 00	0.000E 00
8160.	0.277	0.182E-04	0.172E-04	0.318E 13	0.603E 14	0.199E 05	0.351E-01	0.835E-01	0.000E 00	0.000E 00
7140.	0.292	0.208E-04	0.195E-04	0.218E 13	0.625E 14	0.269E 05	0.608E-01	0.144E 00	0.000E 00	0.000E 00
6120.	0.309	0.242E-04	0.225E-04	0.141E 13	0.639E 14	0.375E 05	0.111E 00	0.256E 00	0.000E 00	0.000E 00
5100.	0.328	0.291E-04	0.266E-04	0.850E 12	0.648E 14	0.547E 05	0.223E 00	0.479E 00	0.000E 00	0.000E 00
4080.	0.352	0.363E-04	0.327E-04	0.460E 12	0.652E 14	0.861E 05	0.512E 00	0.991E 00	0.000E 00	0.000E 00
3060.	0.383	0.484E-04	0.424E-04	0.212E 12	0.655E 14	0.154E 06	0.145E 01	0.244E 01	0.000E 00	0.000E 00
2040.	0.427	0.727E-04	0.605E-04	0.732E 11	0.655E 14	0.346E 06	0.605E 01	0.849E 01	0.000E 00	0.000E 00
1000.	0.504	0.148E-03	0.110E-03	0.124E 11	0.655E 14	0.144E 07	0.675E 02	0.760E 02	0.000E 00	0.000E 00
500.	0.579	0.296E-03	0.222E-03	0.152E 10	0.655E 14	0.576E 07	0.534E 03	0.609E 03	0.000E 00	0.000E 00
480.	0.584	0.309E-03	0.303E-03	0.578E 09	0.655E 14	0.625E 07	0.742E 02	0.684E 03	0.000E 00	0.000E 00
460.	0.588	0.322E-03	0.315E-03	0.510E 09	0.655E 14	0.680E 07	0.876E 02	0.771E 03	0.000E 00	0.000E 00
440.	0.593	0.337E-03	0.330E-03	0.448E 09	0.655E 14	0.744E 07	0.104E 03	0.876E 03	0.000E 00	0.000E 00
420.	0.598	0.353E-03	0.345E-03	0.391E 09	0.655E 14	0.816E 07	0.125E 03	0.100E 04	0.000E 00	0.000E 00
400.	0.603	0.371E-03	0.362E-03	0.339E 09	0.655E 14	0.900E 07	0.151E 03	0.115E 04	0.000E 00	0.000E 00
380.	0.609	0.390E-03	0.380E-03	0.291E 09	0.655E 14	0.997E 07	0.185E 03	0.134E 04	0.000E 00	0.000E 00
360.	0.615	0.412E-03	0.401E-03	0.249E 09	0.655E 14	0.111E 08	0.228E 03	0.157E 04	0.000E 00	0.000E 00
340.	0.621	0.436E-03	0.424E-03	0.210E 09	0.655E 14	0.125E 08	0.285E 03	0.185E 04	0.000E 00	0.000E 00
320.	0.627	0.463E-03	0.450E-03	0.176E 09	0.655E 14	0.141E 08	0.361E 03	0.221E 04	0.000E 00	0.000E 00
300.	0.634	0.494E-03	0.479E-03	0.146E 09	0.655E 14	0.160E 08	0.464E 03	0.268E 04	0.000E 00	0.000E 00
280.	0.642	0.529E-03	0.512E-03	0.120E 09	0.655E 14	0.184E 08	0.606E 03	0.328E 04	0.000E 00	0.000E 00
260.	0.650	0.570E-03	0.550E-03	0.965E 08	0.655E 14	0.213E 08	0.808E 03	0.409E 04	0.000E 00	0.000E 00
240.	0.659	0.618E-03	0.594E-03	0.765E 08	0.655E 14	0.250E 08	0.110E 04	0.519E 04	0.000E 00	0.000E 00
220.	0.668	0.674E-03	0.646E-03	0.596E 08	0.655E 14	0.297E 08	0.154E 04	0.673E 04	0.000E 00	0.000E 00
200.	0.678	0.741E-03	0.707E-03	0.453E 08	0.655E 14	0.360E 08	0.221E 04	0.894E 04	0.000E 00	0.000E 00
180.	0.690	0.823E-03	0.782E-03	0.335E 08	0.655E 14	0.444E 08	0.331E 04	0.123E 05	0.126E-07	0.388E-04
160.	0.702	0.926E-03	0.875E-03	0.239E 08	0.655E 14	0.562E 08	0.518E 04	0.174E 05	0.180E-07	0.595E-04
140.	0.717	0.106E-02	0.993E-03	0.164E 08	0.655E 14	0.735E 08	0.858E 04	0.260E 05	0.268E-07	0.964E-04
120.	0.733	0.124E-02	0.115E-02	0.106E 08	0.655E 14	0.100E 09	0.153E 05	0.412E 05	0.426E-07	0.168E-03
100.	0.753	0.148E-02	0.136E-02	0.640E 07	0.655E 14	0.144E 09	0.301E 05	0.715E 05	0.736E-07	0.322E-03
80.	0.777	0.185E-02	0.167E-02	0.347E 07	0.655E 14	0.225E 09	0.684E 05	0.140E 06	0.144E-06	0.713E-03
60.	0.808	0.247E-02	0.216E-02	0.160E 07	0.655E 14	0.400E 09	0.193E 06	0.333E 06	0.343E-06	0.158E-02
40.	0.852	0.371E-02	0.309E-02	0.552E 06	0.655E 14	0.900E 09	0.803E 06	0.114E 07	0.117E-05	0.824E-02
20.	0.927	0.741E-02	0.556E-02	0.970E 05	0.655E 14	0.360E 10	0.834E 07	0.947E 07	0.976E-05	0.942E-01
10.	1.002	0.148E-01	0.111E-01	0.121E 05	0.655E 14	0.144E 11	0.667E 08	0.762E 08	0.785E-04	0.101E 01

TABLE A1 Calculation of Hydraulic Conductivity From Desorption Data

APPENDIX A - II

PROGRAM LISTING :

CALCULATION OF CONDUCTIVITY FROM DESORPTION DATA

```
      REAL PC(41),S(43),R(43),RBAR(43),N(43),FR(43),R2FR(43),
     *     SUMD(43),L2(43),KR(43),K(43),KS,INTCPT,DR2FR(43)
      READ(5,1) M,J
    1 FORMAT(I2,I2)
      DO 1001 I=1,J
      READ(5,2) INTCPT,SLOPE,SAT,SR
    2 FORMAT (F5.3,F10.7,F9.7,F4.2)
      CALL UNSATK (INTCPT,SLOPE,SAT,SR,M)
 1001 CONTINUE
      WRITE (6,63)
   63 FORMAT(1H1)
      STOP
      END


      SUBROUTINE UNSATK(INTCPT,SLOPE,SAT,SR,M)
      REAL PC(41),S(43),R(43),RBAR(43),N(43),FR(43),R2FR(43),
     *     SUMD(43),L2(43),KR(43),K(43),KS,INTCPT,DR2FR(43)
      DATA PC/15300.,14280.,13260.,12240.,11220.,10200.,9180.,8160.,
     *        7140.,6120.,5100.,4080.,3060.,2040.,
     *        1000.,500.,480.,460.,440.,420.,400.,380.,360.,340.,
     *   320.,300.,280.,260.,240.,220.,200.,180.,160.,140.,120.,
     *   100.,80.,60.,40.,20.,10./
      DATA RBAR(1),N(1),FR(1),DR2FR(1),SUMD(1),R2FR(1)/6*0.0/
      DELTA=1.0E-08
      AREA=0.0
      MD1=M-1
      DO 1002 I=1,M
      S(I)=(ALOG10(PC(I)/1019.89)-INTCPT)/(SLOPE*SAT)
      R(I)=2*72.7/(PC(I)*981.)
 1002 CONTINUE
      DO 1003 I=1,MD1
      RBAR(I+1)=(R(I)+R(I+1))/2.
      DS=S(I+1)-S(I)
      DCP=1./PC(I+1)-1./PC(I)
      N(I+1)=DS/DCP*(1./RBAR(I+1)**2)
      FR(I+1)=FR(I)+N(I+1)
      R2FR(I+1)=R(I+1)**2*FR(I+1)
      DR=R(I+1)-R(I)
      DR2FR(I+1)=(R2FR(I)+R2FR(I+1))*DR/2.
      SUMD(I+1)=SUMD(I)+DR2FR(I+1)
 1003 CONTINUE
      DO 1004 I=1,MD1
      AREA=AREA+(R(I+1)-R(I))*(FR(I)+FR(I+1))/2.
 1004 CONTINUE
      DO 1005 I=1,M
```

```
      L2(I)=SUMD(I)/AREA
      IF(L2(I).LE.DELTA) L2(I)=0.0
 1005 CONTINUE
      KS=L2(41)
      DO 1006 I=1,M
      SE=(S(I)-SR)/(1-SR)
      K(I)=L2(I)*S(I)*SE**2
      KR(I)=K(I)/KS
 1006 CONTINUE
      WRITE(6,61)
   61 FORMAT(1H1,30X,'CALCULATION OF HYDRAULIC CONDUCTIVITY FROM ',
     1'DESORPTION DATA'//9X,'1',10X,'2',10X,'3',10X,'4',10X,'5',10X,
     2'6',10X,'7',10X,'8',10X,'9',9X,'10',9X,'11'/9X,'-',10X,'-',
     310X,'-',10X,'-',10X,'-',10X,'-',10X,'-',10X,'-',10X,'-',9X,
     4'--',9X,'--'//9X,'PC',9X,
     5'S',10X,'R',9X,'RBAR',8X,'N',10X,'FR',8X,'R2FR',6X,'DR2FR',
     67X,'SUMD',7X,'L2',9X,'KR'/)
      DO 1007 I=1,M
      WRITE(6,62) PC(I),S(I),R(I),RBAR(I),N(I),FR(I),R2FR(I),
     1             DR2FR(I),SUMD(I),L2(I),KR(I)
   62 FORMAT(7X,F6.0,5X,F5.3,9E11.3)
 1007 CONTINUE
      RETURN
      END
```

APPENDIX B

FIELD DATA : SOIL MOISTURE CONTENTS

***** DOUBLE FALLOW SOIL MOISTURE BY VOLUME *****

BLOCK	TREATMENT	DEPTH(CM)	8/16/9	11/27/9	4/ 9/0	7/ 1/0	9/17/0	12/ 4/0	1/14/1	3/16/1	5/12/1	6/15/1	7/14/1	7/23/1	9/11/1
1	2	30	0.202	0.315	0.374	0.273	0.296	0.288	0.282	0.302	0.332	0.310	0.0	0.298	0.264
2	2	30	0.160	0.201	0.349	0.362	0.392	0.385	0.377	0.390	0.403	0.394	0.394	0.390	0.388
3	2	30	0.165	0.281	0.372	0.342	0.369	0.349	0.349	0.371	0.368	0.372	0.365	0.395	0.350
AVERAGE		30	0.176	0.266	0.365	0.326	0.352	0.341	0.336	0.354	0.375	0.359	0.253	0.347	0.334
1	2	60	0.161	0.306	0.382	0.289	0.323	0.320	0.317	0.307	0.342	0.331	0.0	0.330	0.320
2	2	60	0.117	0.142	0.351	0.287	0.316	0.314	0.306	0.325	0.351	0.343	0.335	0.332	0.326
3	2	60	0.135	0.168	0.341	0.305	0.338	0.320	0.323	0.336	0.358	0.350	0.346	0.336	0.333
AVERAGE		60	0.138	0.205	0.358	0.294	0.326	0.318	0.315	0.323	0.351	0.341	0.227	0.333	0.326
1	2	90	0.157	0.157	0.362	0.292	0.324	0.317	0.311	0.302	0.336	0.323	0.0	0.326	0.321
2	2	90	0.132	0.132	0.278	0.265	0.295	0.278	0.271	0.278	0.317	0.325	0.310	0.300	0.297
3	2	90	0.122	0.122	0.301	0.244	0.269	0.255	0.255	0.273	0.301	0.293	0.282	0.272	0.265
AVERAGE		90	0.137	0.137	0.314	0.267	0.296	0.283	0.279	0.284	0.319	0.314	0.197	0.299	0.294
1	2	120	0.139	0.139	0.337	0.260	0.276	0.272	0.268	0.252	0.305	0.301	0.0	0.267	0.273
2	2	120	0.141	0.141	0.168	0.231	0.250	0.248	0.238	0.232	0.293	0.303	0.292	0.264	0.274
3	2	120	0.114	0.114	0.263	0.224	0.259	0.229	0.222	0.244	0.266	0.274	0.260	0.253	0.245
AVERAGE		120	0.131	0.131	0.256	0.238	0.262	0.250	0.243	0.243	0.288	0.293	0.184	0.275	0.266
1	2	150	0.141	0.141	0.260	0.221	0.247	0.232	0.227	0.222	0.265	0.261	0.0	0.260	0.245
2	2	150	0.150	0.150	0.159	0.200	0.231	0.229	0.218	0.208	0.256	0.279	0.280	0.266	0.266
3	2	150	0.115	0.115	0.208	0.180	0.204	0.193	0.182	0.185	0.221	0.234	0.221	0.216	0.204
AVERAGE		150	0.135	0.135	0.209	0.200	0.227	0.218	0.209	0.206	0.247	0.265	0.167	0.247	0.239
1	2	180	0.161	0.161	0.188	0.206	0.233	0.230	0.225	0.212	0.253	0.270	0.0	0.258	0.244
2	2	180	0.153	0.153	0.164	0.173	0.217	0.212	0.208	0.200	0.235	0.273	0.279	0.267	0.269
3	2	180	0.115	0.115	0.165	0.159	0.191	0.176	0.176	0.181	0.195	0.218	0.220	0.211	0.203
AVERAGE		180	0.143	0.143	0.172	0.179	0.214	0.206	0.203	0.198	0.229	0.254	0.166	0.245	0.239
1	2	210	0.162	0.162	0.165	0.232	0.232	0.228	0.226	0.215	0.249	0.271	0.0	0.269	0.256
2	2	210	0.139	0.139	0.157	0.149	0.195	0.194	0.190	0.186	0.206	0.248	0.253	0.253	0.249
3	2	210	0.117	0.117	0.161	0.124	0.157	0.151	0.146	0.157	0.167	0.185	0.191	0.186	0.185
AVERAGE		210	0.139	0.139	0.161	0.158	0.195	0.191	0.187	0.186	0.207	0.235	0.148	0.236	0.230
1	2	240	0.159	0.159	0.155	0.168	0.231	0.228	0.226	0.215	0.231	0.283	0.0	0.275	0.266
2	2	240	0.126	0.126	0.143	0.133	0.164	0.168	0.163	0.168	0.176	0.198	0.236	0.231	0.237
3	2	240	0.119	0.119	0.178	0.120	0.147	0.145	0.142	0.150	0.160	0.155	0.176	0.179	0.181
AVERAGE		240	0.135	0.135	0.159	0.140	0.181	0.180	0.177	0.178	0.189	0.213	0.137	0.228	0.228
1	2	270	0.150	0.150	0.140	0.122	0.206	0.208	0.203	0.190	0.195	0.253	0.0	0.256	0.254
2	2	270	0.118	0.118	0.138	0.118	0.140	0.138	0.136	0.129	0.141	0.143	0.184	0.186	0.203
3	2	270	0.114	0.114	0.154	0.128	0.146	0.135	0.137	0.142	0.142	0.143	0.149	0.153	0.165
AVERAGE		270	0.127	0.127	0.144	0.123	0.164	0.160	0.159	0.154	0.161	0.180	0.111	0.198	0.207
1	2	300	0.144	0.144	0.125	0.113	0.175	0.199	0.197	0.185	0.190	0.235	0.0	0.250	0.246
2	2	300	0.115	0.115	0.129	0.105	0.126	0.124	0.123	0.116	0.119	0.120	0.125	0.131	0.166
3	2	300	0.101	0.101	0.135	0.106	0.126	0.119	0.116	0.127	0.118	0.115	0.121	0.119	0.119
AVERAGE		300	0.120	0.120	0.130	0.108	0.142	0.147	0.145	0.143	0.142	0.155	0.082	0.167	0.177
1	2	330	0.139	0.139	0.131	0.101	0.126	0.151	0.166	0.160	0.165	0.194	0.0	0.225	0.223
2	2	330	0.113	0.113	0.123	0.104	0.122	0.124	0.118	0.114	0.122	0.121	0.121	0.117	0.129
3	2	330	0.110	0.110	0.140	0.106	0.124	0.115	0.110	0.110	0.111	0.110	0.115	0.112	0.114
AVERAGE		330	0.121	0.121	0.131	0.104	0.124	0.130	0.131	0.128	0.133	0.142	0.079	0.151	0.155
1	2	360	0.131	0.131	0.130	0.104	0.125	0.135	0.153	0.158	0.163	0.165	0.0	0.230	0.236
2	2	360	0.116	0.116	0.120	0.098	0.121	0.116	0.114	0.108	0.113	0.114	0.115	0.114	0.115
3.	2	360	0.106	0.106	0.130	0.102	0.122	0.113	0.110	0.107	0.110	0.111	0.112	0.114	0.111
AVERAGE		360	0.118	0.118	0.127	0.101	0.123	0.121	0.126	0.124	0.129	0.131	0.076	0.153	0.154
1	2	390	0.127	0.127	0.125	0.102	0.116	0.110	0.120	0.126	0.143	0.155	0.0	0.219	0.235
2	2	390	0.116	0.116	0.119	0.095	0.120	0.111	0.116	0.112	0.116	0.111	0.114	0.116	0.115
3	2	390	0.108	0.108	0.130	0.100	0.115	0.109	0.107	0.107	0.105	0.108	0.109	0.105	0.107
AVERAGE		390	0.117	0.117	0.125	0.099	0.117	0.110	0.114	0.115	0.123	0.125	0.074	0.147	0.152
1	2	420	0.126	0.126	0.124	0.100	0.123	0.125	0.122	0.116	0.115	0.121	0.0	0.163	0.217
2	2	420	0.121	0.121	0.119	0.102	0.121	0.119	0.119	0.113	0.120	0.119	0.119	0.119	0.122
3	2	420	0.110	0.110	0.134	0.100	0.115	0.110	0.110	0.108	0.113	0.110	0.108	0.105	0.107
AVERAGE		420	0.119	0.119	0.126	0.101	0.120	0.118	0.117	0.112	0.116	0.117	0.076	0.129	0.149
1	2	450	0.124	0.124	0.120	0.101	0.120	0.114	0.116	0.113	0.116	0.112	0.0	0.116	0.164
2	2	450	0.115	0.115	0.115	0.100	0.121	0.124	0.118	0.114	0.119	0.116	0.121	0.121	0.118
3	2	450	0.103	0.103	0.138	0.101	0.122	0.115	0.110	0.110	0.105	0.111	0.109	0.114	0.115
AVERAGE		450	0.114	0.114	0.124	0.101	0.121	0.118	0.115	0.112	0.115	0.113	0.077	0.117	0.124

***** DOUBLE FALLOW SOIL MOISTURE BY VOLUME *****

BLOCK	TREATMENT	DEPTH(CM)	3/15/79	11/27/79	4/ 9/80	7/ 1/80	9/17/80	12/ 4/80	1/24/81	3/16/81	5/12/81	6/15/81	7/14/81	7/23/81	9/11/81
1	3	30	0.155	0.229	0.371	0.297	0.292	0.324	0.315	0.339	0.342	0.335	0.0	0.334	0.313
2	3	30	0.214	0.256	0.344	0.194	0.238	0.237	0.231	0.256	0.301	0.279	0.0	0.276	0.262
3	3	30	0.120	0.214	0.350	0.314	0.355	0.348	0.341	0.344	0.379	0.367	0.368	0.371	0.351
AVERAGE		30	0.163	0.236	0.355	0.273	0.295	0.303	0.296	0.313	0.341	0.327	0.123	0.329	0.309
1	3	60	0.141	0.262	0.386	0.304	0.296	0.326	0.332	0.331	0.358	0.353	0.0	0.351	0.341
2	3	60	0.159	0.249	0.344	0.248	0.282	0.283	0.277	0.293	0.330	0.024	0.0	0.337	0.337
3	3	60	0.112	0.126	0.335	0.273	0.312	0.310	0.292	0.295	0.334	0.334	0.331	0.332	0.311
AVERAGE		60	0.141	0.186	0.356	0.232	0.297	0.303	0.300	0.304	0.341	0.237	0.110	0.327	0.323
1	3	90	0.152	0.152	0.356	0.237	0.275	0.273	0.302	0.303	0.326	0.321	0.0	0.324	0.316
2	3	90	0.204	0.294	0.359	0.258	0.319	0.311	0.302	0.301	0.334	0.349	0.0	0.318	0.317
3	3	90	0.116	0.113	0.258	0.243	0.259	0.244	0.238	0.233	0.288	0.262	0.279	0.299	0.272
AVERAGE		90	0.157	0.153	0.326	0.273	0.284	0.233	0.231	0.275	0.316	0.311	0.093	0.310	0.298
1	3	120	0.140	0.140	0.321	0.244	0.224	0.264	0.237	0.242	0.291	0.282	0.0	0.294	0.254
2	3	120	0.171	0.171	0.329	0.257	0.273	0.270	0.264	0.259	0.284	0.299	0.0	0.279	0.277
3	3	120	0.107	0.107	0.148	0.202	0.219	0.212	0.204	0.209	0.252	0.247	0.246	0.240	0.242
AVERAGE		120	0.139	0.139	0.263	0.234	0.239	0.242	0.235	0.237	0.274	0.273	0.082	0.261	0.258
1	3	150	0.138	0.138	0.193	0.220	0.212	0.217	0.216	0.214	0.241	0.241	0.0	0.245	0.233
2	3	150	0.177	0.177	0.273	0.237	0.253	0.244	0.231	0.218	0.247	0.253	0.0	0.251	0.244
3	3	150	0.112	0.112	0.143	0.163	0.134	0.177	0.173	0.174	0.211	0.217	0.222	0.214	0.204
AVERAGE		150	0.142	0.142	0.204	0.207	0.213	0.213	0.207	0.202	0.233	0.240	0.074	0.237	0.233
1	3	180	0.138	0.138	0.132	0.197	0.187	0.191	0.193	0.195	0.219	0.225	0.0	0.221	0.216
2	3	180	0.176	0.176	0.192	0.226	0.246	0.237	0.225	0.221	0.246	0.255	0.0	0.243	0.249
3	3	180	0.115	0.116	0.141	0.135	0.172	0.173	0.160	0.167	0.195	0.216	0.221	0.212	0.211
AVERAGE		180	0.143	0.143	0.155	0.186	0.199	0.200	0.193	0.194	0.220	0.233	0.073	0.225	0.225
1	3	210	0.150	0.150	0.142	0.140	0.187	0.213	0.194	0.201	0.224	0.239	0.0	0.229	0.221
2	3	210	0.170	0.170	0.174	0.212	0.229	0.222	0.211	0.209	0.224	0.248	0.0	0.235	0.233
3	3	210	0.122	0.122	0.144	0.133	0.155	0.147	0.151	0.152	0.156	0.169	0.188	0.188	0.195
AVERAGE		210	0.147	0.147	0.155	0.179	0.190	0.191	0.185	0.187	0.202	0.219	0.063	0.217	0.216
1	3	240	0.154	0.154	0.147	0.136	0.175	0.194	0.197	0.198	0.210	0.226	0.0	0.222	0.219
2	3	240	0.167	0.167	0.172	0.197	0.215	0.216	0.199	0.197	0.200	0.230	0.0	0.223	0.222
3	3	240	0.113	0.118	0.142	0.122	0.145	0.133	0.135	0.134	0.136	0.133	0.144	0.135	0.146
AVERAGE		240	0.146	0.146	0.154	0.168	0.178	0.181	0.177	0.176	0.182	0.196	0.048	0.193	0.196
1	3	270	0.150	0.150	0.145	0.173	0.139	0.215	0.216	0.205	0.219	0.227	0.0	0.245	0.237
2	3	270	0.171	0.171	0.176	0.177	0.211	0.219	0.204	0.203	0.196	0.219	0.0	0.227	0.223
3	3	270	0.112	0.112	0.118	0.116	0.136	0.136	0.123	0.129	0.128	0.128	0.134	0.128	0.125
AVERAGE		270	0.144	0.144	0.153	0.162	0.179	0.184	0.179	0.173	0.178	0.191	0.045	0.200	0.195
1	3	300	0.141	0.141	0.138	0.123	0.159	0.137	0.194	0.202	0.205	0.229	0.0	0.234	0.232
2	3	300	0.166	0.166	0.172	0.146	0.226	0.229	0.213	0.216	0.211	0.218	0.0	0.240	0.236
3	3	300	0.110	0.110	0.136	0.115	0.124	0.122	0.118	0.118	0.120	0.115	0.120	0.114	0.112
AVERAGE		300	0.139	0.139	0.149	0.140	0.173	0.183	0.177	0.179	0.180	0.164	0.040	0.196	0.193
1	3	330	0.137	0.137	0.131	0.118	0.127	0.166	0.171	0.179	0.185	0.134	0.0	0.208	0.213
2	3	330	0.162	0.162	0.161	0.159	0.275	0.200	0.139	0.196	0.197	0.195	0.0	0.214	0.214
3	3	330	0.113	0.113	0.134	0.116	0.134	0.126	0.122	0.131	0.126	0.125	0.126	0.122	0.122
AVERAGE		330	0.137	0.137	0.142	0.131	0.155	0.164	0.164	0.168	0.169	0.168	0.042	0.181	0.183
1	3	360	0.135	0.135	0.129	0.113	0.113	0.133	0.149	0.151	0.166	0.166	0.0	0.165	0.138
2	3	360	0.159	0.159	0.160	0.151	0.192	0.233	0.177	0.194	0.201	0.198	0.0	0.217	0.232
3	3	360	0.109	0.109	0.128	0.176	0.121	0.115	0.116	0.119	0.113	0.110	0.116	0.129	0.113
AVERAGE		360	0.134	0.134	0.139	0.123	0.142	0.159	0.154	0.155	0.160	0.158	0.039	0.170	0.177
1	3	390	0.127	0.127	0.125	0.112	0.114	0.129	0.131	0.132	0.128	0.135	0.0	0.144	0.161
2	3	390	0.150	0.150	0.152	0.191	0.179	0.193	0.194	0.194	0.197	0.195	0.0	0.209	0.235
3	3	390	0.112	0.112	0.125	0.134	0.119	0.118	0.135	0.115	0.111	0.115	0.111	0.114	0.113
AVERAGE		390	0.130	0.130	0.134	0.123	0.137	0.146	0.143	0.147	0.149	0.150	0.037	0.156	0.169
1	3	420	0.126	0.126	0.123	0.102	0.104	0.116	0.116	0.121	0.124	0.120	0.0	0.120	0.119
2	3	420	0.145	0.145	0.147	0.142	0.158	0.177	0.177	0.167	0.191	0.185	0.0	0.200	0.220
3	3	420	0.113	0.113	0.127	0.104	0.120	0.120	0.116	0.120	0.121	0.116	0.113	0.122	0.115
AVERAGE		420	0.129	0.128	0.132	0.116	0.127	0.138	0.136	0.143	0.145	0.142	0.038	0.147	0.151
1	3	450	0.127	0.127	0.120	0.105	0.107	0.120	0.122	0.128	0.127	0.127	0.0	0.123	0.121
2	3	450	0.125	0.128	0.133	0.137	0.148	0.154	0.153	0.167	0.174	0.176	0.0	0.130	0.194
3	3	450	0.111	0.111	0.118	0.102	0.117	0.119	0.118	0.110	0.111	0.107	0.114	0.111	0.137
AVERAGE		450	0.121	0.122	0.124	0.115	0.124	0.128	0.129	0.135	0.137	0.136	[illegible]	[illegible]	[illegible]

***** DOUBLE FALLOW SOIL MOISTURE BY VOLUME *****

BLOCK	TREATMENT	DEPTH(CM)	3/16/79	11/27/79	4/ 9/80	7/ 1/80	9/17/80	12/ 4/80	1/14/81	3/16/81	5/12/81	6/15/81	7/14/81	7/23/81	9/11/81
1	4	30	0.294	0.274	0.390	0.268	0.294	0.256	0.292	0.338	0.334	0.338	0.0	0.295	0.291
2	4	30	0.175	0.264	0.373	0.270	0.314	0.308	0.311	0.324	0.344	0.357	0.343	0.331	0.337
3	4	30	0.141	0.230	0.352	0.353	0.354	0.351	0.356	0.365	0.381	0.368	0.370	0.334	0.361
AVERAGE		30	0.173	0.234	0.372	0.297	0.321	0.312	0.310	0.342	0.360	0.354	0.238	0.335	0.330
1	4	60	0.141	0.232	0.366	0.324	0.342	0.346	0.345	0.346	0.355	0.360	0.0	0.347	0.339
2	4	60	0.133	0.162	0.352	0.310	0.342	0.333	0.335	0.326	0.360	0.355	0.352	0.344	0.347
3	4	60	0.121	0.129	0.338	0.311	0.304	0.291	0.239	0.289	0.337	0.349	0.342	0.347	0.339
AVERAGE		60	0.132	0.174	0.352	0.315	0.329	0.323	0.323	0.320	0.351	0.355	0.231	0.346	0.341
1	4	90	0.213	0.213	0.363	0.294	0.317	0.312	0.319	0.310	0.327	0.342	0.0	0.326	0.313
2	4	90	0.151	0.151	0.305	0.270	0.291	0.264	0.277	0.268	0.305	0.300	0.303	0.299	0.291
3	4	90	0.116	0.116	0.257	0.220	0.224	0.276	0.234	0.233	0.253	0.271	0.254	0.266	0.249
AVERAGE		90	0.162	0.162	0.338	0.261	0.277	0.268	0.260	0.260	0.296	0.304	0.139	0.297	0.283
1	4	120	0.144	0.144	0.323	0.293	0.254	0.267	0.247	0.249	0.293	0.297	0.0	0.276	0.273
2	4	120	0.158	0.156	0.220	0.220	0.236	0.226	0.217	0.223	0.252	0.249	0.242	0.241	0.239
3	4	120	0.113	0.113	0.133	0.194	0.213	0.136	0.182	0.183	0.235	0.275	0.260	0.247	0.237
AVERAGE		120	0.138	0.138	0.225	0.224	0.234	0.224	0.215	0.218	0.257	0.274	0.167	0.255	0.244
1	4	150	0.140	0.140	0.263	0.240	0.246	0.228	0.226	0.226	0.249	0.230	0.0	0.258	0.251
2	4	150	0.141	0.141	0.146	0.189	0.209	0.274	0.191	0.193	0.217	0.229	0.219	0.215	0.214
3	4	150	0.117	0.117	0.121	0.160	0.170	0.159	0.151	0.154	0.197	0.249	0.240	0.224	0.219
AVERAGE		150	0.133	0.133	0.177	0.196	0.223	0.220	0.189	0.191	0.221	0.253	0.153	0.232	0.223
1	4	180	0.145	0.145	0.173	0.208	0.219	0.215	0.209	0.209	0.223	0.254	0.0	0.237	0.231
2	4	180	0.137	0.137	0.140	0.166	0.181	0.181	0.176	0.163	0.190	0.198	0.202	0.195	0.192
3	4	180	0.124	0.124	0.127	0.135	0.193	0.146	0.142	0.143	0.171	0.245	0.245	0.215	0.233
AVERAGE		180	0.135	0.135	0.147	0.170	0.198	0.181	0.176	0.172	0.195	0.232	0.149	0.222	0.218
1	4	210	0.165	0.165	0.164	0.209	0.227	0.225	0.224	0.222	0.223	0.262	0.0	0.247	0.242
2	4	210	0.129	0.129	0.132	0.141	0.168	0.153	0.159	0.151	0.160	0.178	0.131	0.183	0.181
3	4	210	0.134	0.134	0.137	0.124	0.136	0.129	0.129	0.125	0.134	0.214	0.212	0.204	0.205
AVERAGE		210	0.143	0.143	0.144	0.158	0.177	0.173	0.171	0.166	0.172	0.218	0.131	0.211	0.209
1	4	240	0.166	0.166	0.160	0.199	0.212	0.217	0.213	0.214	0.299	0.239	0.0	0.267	0.237
2	4	240	0.123	0.123	0.123	0.107	0.136	0.135	0.131	0.124	0.136	0.126	0.148	0.167	0.150
3	4	240	0.127	0.127	0.130	0.123	0.149	0.137	0.135	0.132	0.137	0.191	0.227	0.217	0.224
AVERAGE		240	0.139	0.139	0.138	0.146	0.165	0.163	0.160	0.156	0.161	0.169	0.125	0.204	0.204
1	4	270	0.165	0.165	0.155	0.158	0.135	0.197	0.181	0.184	0.175	0.210	0.0	0.208	0.276
2	4	270	0.128	0.128	0.132	0.135	0.126	0.126	0.124	0.129	0.133	0.137	0.140	0.138	0.146
3	4	270	0.119	0.119	0.121	0.116	0.123	0.123	0.124	0.113	0.117	0.115	0.145	0.157	0.151
AVERAGE		270	0.137	0.137	0.136	0.126	0.145	0.145	0.141	0.142	0.142	0.151	0.095	0.168	0.179
1	4	300	0.163	0.163	0.141	0.141	0.134	0.191	0.193	0.190	0.178	0.188	0.0	0.212	0.213
2	4	300	0.119	0.119	0.122	0.116	0.143	0.140	0.137	0.133	0.137	0.135	0.143	0.140	0.137
3	4	300	0.117	0.117	0.118	0.110	0.117	0.110	0.111	0.108	0.137	0.107	0.115	0.111	0.143
AVERAGE		300	0.132	0.132	0.127	0.122	0.148	0.147	0.147	0.144	0.141	0.145	0.096	0.154	0.164
1	4	330	0.144	0.144	0.133	0.118	0.145	0.159	0.163	0.164	0.164	0.170	0.0	0.131	0.192
2	4	330	0.113	0.113	0.116	0.096	0.116	0.111	0.111	0.106	0.112	0.115	0.114	0.114	0.113
3	4	330	0.119	0.119	0.119	0.111	0.123	0.114	0.113	0.115	0.113	0.114	0.124	0.111	0.112
AVERAGE		330	0.125	0.125	0.123	0.118	0.129	0.129	0.129	0.128	0.130	0.133	0.079	0.136	0.139
1	4	360	0.132	0.132	0.129	0.131	0.117	0.124	0.127	0.129	0.132	0.138	0.0	0.134	0.149
2	4	360	0.112	0.112	0.116	0.093	0.111	0.109	0.107	0.107	0.105	0.105	0.111	0.110	0.109
3	4	360	0.114	0.114	0.118	0.135	0.118	0.110	0.109	0.109	0.113	0.112	0.115	0.110	0.113
AVERAGE		360	0.119	0.119	0.121	0.130	0.115	0.114	0.114	0.115	0.113	0.120	0.075	0.118	0.124
1	4	390	0.129	0.129	0.127	0.116	0.129	0.136	0.129	0.135	0.135	0.141	0.0	0.139	0.144
2	4	390	0.116	0.116	0.117	0.100	0.114	0.110	0.107	0.111	0.111	0.111	0.116	0.114	0.111
3	4	390	0.114	0.114	0.115	0.113	0.124	0.113	0.109	0.111	0.111	0.109	0.117	0.106	0.111
AVERAGE		390	0.120	0.120	0.120	0.109	0.123	0.120	0.115	0.119	0.120	0.122	0.078	0.120	0.122
1	4	420	0.123	0.123	0.129	0.108	0.126	0.122	0.119	0.121	0.122	0.126	0.0	0.123	0.124
2	4	420	0.113	0.113	0.115	0.097	0.114	0.111	0.109	0.106	0.110	0.114	0.113	0.107	0.109
3	4	420	0.117	0.116	0.117	0.105	0.112	0.111	0.110	0.114	0.109	0.109	0.113	0.105	0.111
AVERAGE		420	0.118	0.117	0.120	0.103	0.117	0.115	0.113	0.110	0.114	0.116	0.075	0.112	0.115
1	4	450	0.124	0.124	0.119	0.109	0.122	0.126	0.116	0.126	0.123	0.125	0.0	0.118	0.121
2	4	450	0.117	0.117	0.117	0.093	0.111	0.109	0.107	0.104	0.112	0.111	0.109	0.109	0.109
3	4	450	0.115	0.115	0.116	0.125	0.113	0.110	0.104	0.107	0.107	0.106	0.112	0.111	0.109
AVERAGE		450	0.119	0.119	0.117	0.102	0.115	0.115	0.109	0.112	0.114	0.114	0.074	0.113	0.113

***** DOUBLE FALLOW SOIL MOISTURE BY VOLUME *****

BLOCK	TREATMENT	DEPTH(CM)	8/16/9	11/27/9	4/ 9/0	7/ 1/0	9/17/0	12/ 4/0	1/14/1	3/16/1	5/12/1	6/15/1	7/14/1	7/28/1	9/11/1
1	5	30	0.172	0.314	0.363	0.328	0.351	0.331	0.320	0.355	0.358	0.361	0.0	0.330	0.328
2	5	30	0.146	0.197	0.344	0.340	0.369	0.349	0.353	0.374	0.275	0.359	0.361	0.355	0.355
3	5	30	0.179	0.229	0.383	0.336	0.363	0.344	0.348	0.374	0.384	0.368	0.369	0.351	0.384
AVERAGE		30	0.163	0.247	0.363	0.335	0.361	0.341	0.340	0.368	0.339	0.363	0.243	0.345	0.344
1	5	60	0.137	0.234	0.365	0.311	0.351	0.341	0.333	0.333	0.351	0.352	0.0	0.337	0.330
2	5	60	0.113	0.136	0.350	0.347	0.324	0.318	0.304	0.327	0.337	0.330	0.330	0.323	0.316
3	5	60	0.128	0.157	0.339	0.327	0.372	0.359	0.350	0.368	0.382	0.380	0.376	0.366	0.373
AVERAGE		60	0.126	0.166	0.351	0.345	0.349	0.336	0.329	0.346	0.357	0.354	0.235	0.342	0.340
1	5	90	0.151	0.152	0.307	0.298	0.320	0.305	0.286	0.299	0.348	0.330	0.0	0.339	0.307
2	5	90	0.125	0.125	0.244	0.258	0.267	0.262	0.262	0.270	0.302	0.299	0.292	0.285	0.278
3	5	90	0.137	0.137	0.229	0.253	0.294	0.269	0.265	0.291	0.331	0.319	0.311	0.291	0.295
AVERAGE		90	0.138	0.138	0.260	0.266	0.300	0.279	0.272	0.287	0.327	0.316	0.201	0.299	0.293
1	5	120	0.128	0.128	0.231	0.237	0.260	0.242	0.253	0.233	0.292	0.297	0.0	0.259	0.241
2	5	120	0.139	0.139	0.148	0.218	0.250	0.251	0.247	0.248	0.299	0.310	0.294	0.287	0.293
3	5	120	0.154	0.154	0.162	0.237	0.238	0.223	0.215	0.234	0.285	0.290	0.275	0.253	0.251
AVERAGE		120	0.140	0.140	0.180	0.227	0.253	0.238	0.232	0.238	0.292	0.296	0.190	0.266	0.258
1	5	150	0.130	0.130	0.153	0.209	0.236	0.224	0.213	0.207	0.257	0.276	0.0	0.249	0.229
2	5	150	0.119	0.119	0.129	0.229	0.260	0.247	0.243	0.242	0.291	0.314	0.300	0.293	0.282
3	5	150	0.162	0.162	0.170	0.202	0.234	0.223	0.222	0.222	0.279	0.301	0.286	0.273	0.260
AVERAGE		150	0.137	0.137	0.151	0.213	0.243	0.230	0.226	0.224	0.276	0.297	0.195	0.272	0.257
1	5	180	0.142	0.142	0.143	0.173	0.210	0.233	0.173	0.187	0.234	0.262	0.0	0.231	0.221
2	5	180	0.111	0.111	0.114	0.144	0.147	0.178	0.171	0.172	0.220	0.236	0.233	0.224	0.208
3	5	180	0.173	0.173	0.178	0.193	0.236	0.234	0.225	0.222	0.281	0.309	0.302	0.293	0.279
AVERAGE		180	0.142	0.142	0.145	0.170	0.211	0.204	0.190	0.194	0.245	0.269	0.178	0.249	0.236
1	5	210	0.144	0.144	0.153	0.132	0.189	0.187	0.173	0.178	0.212	0.253	0.0	0.229	0.210
2	5	210	0.113	0.113	0.113	0.096	0.156	0.169	0.167	0.166	0.204	0.252	0.237	0.236	0.228
3	5	210	0.178	0.178	0.177	0.166	0.230	0.226	0.222	0.228	0.266	0.303	0.305	0.288	0.287
AVERAGE		210	0.145	0.145	0.148	0.131	0.192	0.194	0.187	0.191	0.227	0.269	0.181	0.251	0.242
1	5	240	0.143	0.143	0.153	0.133	0.181	0.157	0.170	0.192	0.211	0.281	0.0	0.271	0.260
2	5	240	0.122	0.122	0.122	0.096	0.119	0.135	0.146	0.152	0.170	0.266	0.255	0.248	0.243
3	5	240	0.159	0.159	0.158	0.153	0.179	0.208	0.207	0.210	0.220	0.291	0.294	0.230	0.279
AVERAGE		240	0.141	0.141	0.146	0.127	0.166	0.177	0.181	0.185	0.200	0.279	0.183	0.266	0.261
1	5	270	0.142	0.142	0.151	0.122	0.149	0.163	0.163	0.167	0.171	0.272	0.0	0.260	0.245
2	5	270	0.119	0.119	0.119	0.105	0.124	0.118	0.120	0.123	0.128	0.251	0.256	0.259	0.257
3	5	270	0.144	0.144	0.147	0.129	0.156	0.175	0.175	0.150	0.181	0.257	0.273	0.253	0.257
AVERAGE		270	0.135	0.135	0.139	0.119	0.143	0.152	0.153	0.157	0.160	0.260	0.176	0.257	0.253
1	5	300	0.134	0.134	0.131	0.120	0.141	0.140	0.137	0.144	0.149	0.257	0.0	0.255	0.245
2	5	300	0.114	0.114	0.116	0.100	0.119	0.114	0.115	0.115	0.119	0.164	0.247	0.251	0.247
3	5	300	0.131	0.131	0.132	0.119	0.143	0.138	0.147	0.149	0.160	0.213	0.247	0.244	0.250
AVERAGE		300	0.126	0.126	0.126	0.113	0.134	0.131	0.133	0.136	0.143	0.211	0.165	0.250	0.247
1	5	330	0.125	0.125	0.137	0.110	0.130	0.128	0.123	0.125	0.128	0.209	0.0	0.247	0.239
2	5	330	0.113	0.113	0.114	0.095	0.111	0.104	0.104	0.101	0.104	0.112	0.171	0.198	0.223
3	5	330	0.126	0.126	0.124	0.105	0.130	0.124	0.124	0.128	0.128	0.130	0.227	0.221	0.233
AVERAGE		330	0.121	0.121	0.125	0.103	0.124	0.120	0.117	0.118	0.120	0.150	0.133	0.222	0.232
1	5	360	0.122	0.122	0.133	0.110	0.133	0.124	0.126	0.121	0.116	0.125	0.0	0.226	0.230
2	5	360	0.116	0.116	0.115	0.095	0.113	0.110	0.111	0.110	0.113	0.112	0.114	0.117	0.198
3	5	360	0.121	0.121	0.120	0.097	0.121	0.119	0.119	0.116	0.121	0.116	0.130	0.172	0.221
AVERAGE		360	0.120	0.120	0.123	0.101	0.122	0.118	0.119	0.116	0.117	0.118	0.081	0.172	0.216
1	5	390	0.120	0.120	0.128	0.118	0.132	0.128	0.132	0.120	0.122	0.130	0.0	0.200	0.229
2	5	390	0.111	0.110	0.113	0.093	0.114	0.105	0.107	0.110	0.106	0.107	0.108	0.108	0.112
3	5	390	0.116	0.116	0.117	0.096	0.123	0.118	0.116	0.115	0.113	0.119	0.121	0.113	0.180
AVERAGE		390	0.115	0.115	0.119	0.102	0.123	0.117	0.118	0.115	0.114	0.119	0.076	0.140	0.174
1	5	420	0.120	0.120	0.120	0.125	0.120	0.113	0.118	0.113	0.116	0.116	0.0	0.119	0.195
2	5	420	0.114	0.114	0.114	0.091	0.118	0.102	0.102	0.104	0.105	0.104	0.108	0.110	0.137
3	5	420	0.117	0.117	0.117	0.088	0.117	0.109	0.111	0.105	0.111	0.108	0.117	0.108	0.112
AVERAGE		420	0.117	0.117	0.117	0.095	0.118	0.110	0.110	0.109	0.111	0.109	0.075	0.112	0.138
1	5	450	0.121	0.121	0.120	0.097	0.113	0.111	0.106	0.107	0.108	0.106	0.0	0.110	0.119
2	5	450	0.118	0.118	0.119	0.096	0.118	0.110	0.115	0.116	0.111	0.110	0.115	0.112	0.113
3	5	450	0.112	0.112	0.111	0.087	0.117	0.110	0.102	0.101	0.111	0.105	0.107	0.104	0.105
AVERAGE		450	0.117	0.117	0.117	0.093	0.116	0.110	0.108	0.108	0.110	0.107	0.074	0.109	0.112

***** DOUBLE FALLOW SOIL MOISTURE BY VOLUME *****

BLOCK	TREATMENT	DEPTH(CM)	8/16/9	11/27/9	4/ 9/0	7/ 1/0	9/17/0	12/ 4/0	1/14/1	3/16/1	5/12/1	6/15/1	7/14/1	7/28/1	9/11/1
1	6	30	0.197	0.220	0.360	0.301	0.269	0.300	0.268	0.338	0.342	0.325	0.0	0.295	0.314
2	6	30	0.170	0.204	0.354	0.336	0.364	0.314	0.349	0.366	0.378	0.355	0.349	0.344	0.351
3	6	30	0.159	0.218	0.395	0.338	0.396	0.372	0.360	0.290	0.395	0.394	0.369	0.375	0.364
AVERAGE		30	0.175	0.214	0.370	0.325	0.340	0.325	0.332	0.365	0.372	0.356	0.239	0.339	0.343
1	6	60	0.147	0.212	0.377	0.315	0.298	0.331	0.326	0.342	0.348	0.354	0.0	0.332	0.334
2	6	60	0.134	0.163	0.342	0.319	0.353	0.346	0.348	0.363	0.369	0.364	0.359	0.355	0.351
3	6	60	0.124	0.141	0.341	0.332	0.377	0.359	0.359	0.363	0.379	0.385	0.372	0.373	0.366
AVERAGE		60	0.135	0.172	0.353	0.322	0.343	0.345	0.344	0.355	0.365	0.368	0.244	0.353	0.350
1	6	90	0.156	0.156	0.290	0.319	0.301	0.346	0.333	0.345	0.350	0.353	0.0	0.336	0.332
2	6	90	0.145	0.152	0.259	0.253	0.239	0.271	0.266	0.277	0.306	0.296	0.294	0.234	0.283
3	6	90	0.125	0.125	0.304	0.249	0.274	0.256	0.246	0.264	0.275	0.287	0.269	0.269	0.257
AVERAGE		90	0.142	0.144	0.284	0.274	[illegible]	0.291	0.287	0.295	0.310	0.312	0.189	0.296	0.291
1	6	120	0.146	0.146	0.162	0.244	0.233	0.260	0.247	0.260	0.285	0.303	0.0	0.230	0.272
2	6	120	0.139	0.155	0.193	0.218	0.236	0.230	0.224	0.336	0.275	0.293	0.262	0.254	0.150
3	6	120	0.138	0.138	0.312	0.234	0.246	0.218	0.215	0.216	0.255	0.269	0.241	0.242	0.227
AVERAGE		120	0.141	0.146	0.222	0.232	0.238	0.236	0.230	0.271	0.272	0.285	0.166	0.255	0.216
1	6	150	0.158	0.158	0.161	0.204	0.193	0.225	0.216	0.221	0.254	0.273	0.0	0.245	0.237
2	6	150	0.151	0.151	0.167	0.206	0.229	0.220	0.224	0.214	0.256	0.273	0.265	0.252	0.247
3	6	150	0.133	0.133	0.351	0.235	0.254	0.227	0.217	0.218	0.252	0.284	0.255	0.254	0.237
AVERAGE		150	0.147	0.147	0.226	0.215	0.227	0.224	0.219	0.218	0.254	0.277	0.175	0.250	0.240
1	6	180	0.160	0.160	0.161	0.185	0.191	0.212	0.209	0.221	0.238	0.271	0.0	0.246	0.239
2	6	180	0.155	0.155	0.172	0.164	0.204	0.230	0.198	0.194	0.228	0.253	0.247	0.242	0.234
3	6	180	0.139	0.129	0.159	0.209	0.233	0.239	0.204	0.201	0.234	0.265	0.236	0.241	0.229
AVERAGE		180	0.151	0.151	0.164	0.186	0.208	0.207	0.204	0.205	0.233	0.263	0.181	0.243	0.234
1	6	210	0.156	0.156	0.160	0.154	0.176	0.238	0.199	0.207	0.222	0.262	0.0	0.239	0.233
2	6	210	0.140	0.140	0.158	0.157	0.202	0.199	0.199	0.198	0.211	0.243	0.246	0.237	0.240
3	6	210	0.151	0.151	0.152	0.227	0.250	0.239	0.238	0.229	0.252	0.295	0.274	0.277	0.269
AVERAGE		210	0.149	0.149	0.157	0.179	0.209	0.215	0.212	0.211	0.228	0.267	0.173	0.251	0.247
1	6	240	0.155	0.155	0.157	0.136	0.162	0.187	0.186	0.193	0.194	0.245	0.0	0.228	0.225
2	6	240	0.132	0.132	0.155	0.131	0.167	0.171	0.171	0.165	0.172	0.207	0.222	0.212	0.215
3	6	240	0.137	0.137	0.141	0.224	0.263	0.259	0.252	0.242	0.255	0.296	0.285	0.294	0.280
AVERAGE		240	0.141	0.141	0.151	0.164	0.197	0.206	0.203	0.200	0.209	0.249	0.169	0.245	0.240
1	6	270	0.146	0.146	0.148	0.132	0.141	0.178	0.178	0.164	0.181	0.231	0.0	0.227	0.222
2	6	270	0.135	0.135	0.163	0.132	0.156	0.157	0.159	0.155	0.163	0.173	0.203	0.195	0.206
3	6	270	0.124	0.124	0.125	0.162	0.222	0.218	0.239	0.213	0.214	0.267	0.267	0.271	0.261
AVERAGE		270	0.135	0.135	0.145	0.142	0.173	0.184	0.192	0.186	0.186	0.224	0.157	0.231	0.233
1	6	300	0.139	0.139	0.140	0.135	0.129	0.168	0.173	0.178	0.175	0.219	0.0	0.243	0.232
2	6	300	0.123	0.123	0.152	0.146	0.168	0.166	0.166	0.167	0.172	0.169	0.195	0.204	0.222
3	6	300	0.114	0.114	0.116	0.109	0.184	0.200	0.199	0.204	0.202	0.251	0.260	0.270	0.265
AVERAGE		300	0.125	0.125	0.136	0.130	0.160	0.178	0.179	0.183	0.183	0.213	0.153	0.239	0.240
1	6	330	0.135	0.135	0.140	0.119	0.124	0.142	0.149	0.160	0.157	0.171	0.0	0.233	0.228
2	6	330	0.122	0.122	0.159	0.128	0.147	0.150	0.146	0.143	0.148	0.145	0.157	0.147	0.184
3	6	330	0.115	0.115	0.117	0.095	0.118	0.136	0.146	0.155	0.153	0.176	0.211	0.224	0.222
AVERAGE		330	0.124	0.124	0.139	0.114	0.130	0.143	0.147	0.153	0.153	0.164	0.123	0.201	0.211
1	6	360	0.125	0.125	0.131	0.113	0.113	0.131	0.131	0.138	0.137	0.143	0.0	0.271	0.211
2	6	360	0.119	0.119	0.155	0.127	0.149	0.140	0.125	0.137	0.157	0.137	0.140	0.140	0.146
3	6	360	0.110	0.110	0.108	0.092	0.117	0.106	0.114	0.112	0.116	0.130	0.153	0.183	0.209
AVERAGE		360	0.118	0.118	0.131	0.111	0.126	0.126	0.124	0.129	0.130	0.137	0.098	0.175	0.189
1	6	390	0.120	0.120	0.126	0.107	0.105	0.126	0.119	0.125	0.121	0.122	0.0	0.130	0.200
2	6	390	0.117	0.117	0.142	0.126	0.142	0.141	0.140	0.134	0.137	0.134	0.135	0.131	0.138
3	6	390	0.110	0.110	0.110	0.093	0.106	0.102	0.098	0.106	0.101	0.104	0.101	0.102	0.140
AVERAGE		390	0.116	0.116	0.126	0.109	0.117	0.123	0.119	0.121	0.120	0.120	0.079	0.121	0.159
1	6	420	0.117	0.117	0.121	0.105	0.097	0.115	0.115	0.126	0.115	0.120	0.0	0.119	0.142
2	6	420	0.116	0.116	0.145	0.118	0.135	0.135	0.131	0.125	0.131	0.124	0.128	0.126	0.124
3	6	420	0.111	0.111	0.110	0.095	0.116	0.111	0.105	0.109	0.105	0.105	0.109	0.107	0.104
AVERAGE		420	0.115	0.115	0.125	0.106	0.116	0.120	0.117	0.120	0.117	0.118	0.079	0.117	0.123
1	6	450	0.119	0.119	0.122	0.101	0.102	0.114	0.118	0.118	0.113	0.114	0.0	0.113	0.113
2	6	450	0.111	0.111	0.141	0.126	0.142	0.133	0.141	0.127	0.133	0.124	0.136	0.131	0.139
3	6	450	0.115	0.115	0.116	0.116	0.119	0.116	0.114	0.112	0.115	0.118	0.109	0.114	0.115
AVERAGE		450	0.115	0.115	0.126	0.114	0.121	0.123	0.124	0.119	0.120	0.120	0.082	0.119	0.122

APPENDIX C

PROGRAM LISTING : SHORT-TERM MODEL

```
C   *************************************************************
C   *                                                           *
C   *  1. THIS IS A SIMPLIFIED RECHARG2 MODEL.                  *
C   *  2. THE  PURPOSE  OF THIS PROGRAM IS TO MODEL  SOIL MOISTURE *
C   *     DISTRIBUTION  AND  MOVEMENT WITHIN THE TOP 450 CM OF THE *
C   *     SOIL PROFILE DURING THE DOUBLE FALLOW PERIOD.         *
C   *  3. NO  CROP  ROTATIONS,  NO  CANOPY  EFFECTS  AND  NO  ROOT *
C   *     EXTRACTION PATTERNS  WERE  CONSIDERED IN THIS SIMPLIFIED *
C   *     MODEL.                                                *
C   *                                                           *
C   *************************************************************
      INTEGER NDIM(12),T(2),FDAY(2)
      INTEGER YSTART,YEND,YEARS,YEAR,WSERAT
      INTEGER SOIL, AREA, AR, CROP
      REAL LAIC(2)
      REAL IA,IAET,IAADD,EO,MA,MR,M,LAI,KC(7,12),INFIL(17),LEN(16)
      REAL KSAT,SAT(16)
      DIMENSION AVLFC(16),AVLSM(16),IAADD(2)
      DIMENSION EEACCT(13,8),AMONTH(13)
      DIMENSION TRANSP(16),SM(16,6,2),SMP(16,6,2),EXTRA(15),
     1          SMAVI(15)
      DIMENSION SMSAT(15),Q(15),H(16),COND(16),RCN(12,7),RCM(12,7)
      DIMENSION POND(2),U(12),CC(12),FCU(16),PWP(16),WSACCT(13,8)
      DIMENSION RA(12),C(16),D(16),WF(16),REFF(2)
      DIMENSION ECL(12,7)
C   ********************************
C   *                              *
C   *  INITIALIZATION OF VARIABLES *
C   *                              *
C   ********************************
      DATA LAIC/2*0.0/
      DATA LEN/2*15.24,14*30.48/
      DATA PERC,DPERC,RCHG,RCHGR,RCHGS/5*0.0/
      DATA IA,IAET,IAADD,LAI,AETTOT,SMOIST,PDT/7*0.0,37.5/
      DATA PACK,MA,M,MR,PACKPY/5*0.0/
      DATA SOIL, CROP/3,7/
      DATA COND,H,POND/16*0.005,16*1500.0,2*0.0/
      DATA INFIL,TRANSP,EXTRA/48*0.0/
      DATA NDIM/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA AMONTH/'JAN.','FEB.','MAR.','APR.','MAY ','JUNE','JULY',
     1'AUG.','SEPT','OCT.','NOV.','DEC.','TOT.'/
      DATA U/0.47,0.47,0.39,0.39,0.39,0.39,0.35,0.35,0.31,0.31,0.28,
     10.24/
      DATA CC/0.2,0.2,0.177,0.177,0.177,0.177,0.159,0.159,0.138,
     10.138,0.134,0.131/
      DATA FCU/1.78,1.94,3.86,3.6,3.1,11*3.0/
      DATA PWP /0.59,1.21,2*1.2,0.76,0.82,0.57,8*1.21,1.27/
      DATA C /4.647,9.366,4.346,3.687,4.346,11*3.388/
      DATA D /-19.713,-33.042,-16.416,-15.465,-16.416,11*-14.303/
```

```
      DATA FDAY/31,31/
       DATA ALPH,WSBRAT,MSTART,MEND,YSTART,YEND/1.3,4,8,12,79,81/
      DATA SM/1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3         1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3         1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3         1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3         1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3         1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62/
      DATA SMPD1,SMPD2/2*27.18/
      DATA KSAT,SAT/10.00,0.4695,0.4235,2*0.5453,0.5362,0.62,0.5589,
     1              5*0.4569,0.4446,0.4424,0.4426,0.3987/
C     *********************
C     *                   *
C     *  READ INPUT DATA  *
C     *                   *
C     *********************
      READ(5,1)   ((RCN(I,K),K=1,7),I=1,12)
    1 FORMAT(7(F2.0,1X))
      READ(5,2)   ((KC(I,K),K=1,12),I=1,7)
    2 FORMAT( 12(F3.2,1X))
      READ(5,3)  (RA(I),I=1,12)
    3 FORMAT(12F4.2)
      XYZ=0.0
      YEARS=YEND-YSTART+1
C                   ---------------------
C                   |                   |
C            *****  | ENTER YEARLY LOOP |  *****
C                   |                   |
C                   ---------------------
      KROP=7
      DO 1001 NY=1,YEARS
      DO 1002 I=1,13
      DO 1003 J=1,8
      WSACCT(I,J)=0.0
 1003 BEACCT(I,J)=0.0
 1002 CONTINUE
      IF(NY.GT.1) MSTART=1
      IF (NY.EQ.YEARS) MEND=8
      NDAY=0
      YEAR= 78+NY
      WRITE (6,61)
   61 FORMAT(1H1,3X)
      WRITE (6,62)
```

```
   62 FORMAT(29X,'***** DAILY SOIL MOISTURES  ( % ) FCR WATERSHED AN'
     1,'D BENCH AREAS FOR EACH LAYER *****'//12X,'DATE',9X,'1',6X,
     2'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',6X,'9',5X,'10',
     35X,'11',5X,'12',5X,'13',5X,'14',5X,'15'/11X,'------',7X,'---'
     44X,'---',4X,'---',4X,'---',4X,'---',4X,'---',4X,'---',4X,'---'
     5,4X,'---',4X,'----',3X,'----',3X,'----',3X,'----',3X,'----',
     63X,'----'//)
C                  ---------------------
C                  |                   |
C          ***** | ENTER MONHTLY LOOP | *****
C                  |                   |
C                  ---------------------
      DO 1004 NM=MSTART,MEND
      IF (NM.NE.2) GO TO 101
      NN=YEAR/4*4
      IF(NN.NE.YEAR) GO TO 102
      NN=YEAR/100*100
      IF(NN.EQ.YEAR) GO TO 102
      NDIM(2)=29
      GO TO 101
  102 NDIM(2)=28
  101 NDAYS=NDIM(NM)
      R=0.23
C                  -------------------
C                  |                 |
C          ***** | ENTER DAILY LOOP | *****
C                  |                 |
C                  -------------------
      DO 1005 ND=1,NDAYS
C
C   ***********************************************************
C   *                                                         *
C   *  CALCULATION OF POTENTIAL EVAPOTRANSPIRATION ( PET )    *
C   *                      BY  MEANS  OF                      *
C   *               PENMAN  COMBINATION  EQUATION             *
C   *                                                         *
C   ***********************************************************
      READ (5,4) NOFDAY, TMAX,TMIN,RHD,RS,WIND,PREC
    4 FORMAT (I3,1X,2F3.0,F2.0,F4.0,F3.0,F4.2)
      TMAX=TMAX-100.
      TMIN=TMIN-100.
      TAVG=(TMAX+TMIN)/2.
      CENT=(TAVG-32.)*100./180.
      ABST=CENT+273.16
      ES=33.9*((0.00738*CENT+0.8072)**8-0.000019*ABS(1.8*CENT+48)
     1  +0.00136)
      ESA=ES*RHD/100.
      RS=RS/58.6
      S=1.818*(RS/RA(NM))-0.327
      B=2.01E-09*ABST**4
      RN=RS*(1-R)-B*(0.56-0.092*SQRT(ESA))*(0.1+0.9*S)
      WINDD= WIND*0.555
      EA=0.35*(0.5+0.01*WINDD)*(ES-ESA)
      IF(TAVG)103,103,104
```

```
  103 DELTA=0.0
      GO TO 201
  104 DELTA=0.039*TAVG**0.673
  201 GAMMA=1.-DELTA
      PET=((DELTA*RN)+(GAMMA*EA))/25.39998
      PDT=TAVG
      IF(TAVG.LT.20.0) PET=0.0
      IF(PET.LT.0.0) PET=0.0
      AADD=IAADD(1)
      IF(PET-AADD) 105,105,106
  105 AADD=AADD-PET
      IF(AADD.LT.0.0) AADD=0.0
      PET=0.0
      GO TO 202
  106 PET=PET-AADD
  202 DO 1006 AR=1,2
      IAADD(AR)=AADD
 1006 CONTINUE
C   **************************************************
C   *                                                *
C   *  CALCULATION OF MOISTURE ADDED DUE TO SNOWMELT *
C   *                                                *
C   **************************************************
      M=0.0
      AETSNO=0.0
      PRECIP=PREC
      RAIN=PRECIP
      TRANST=0.0
      IF(PACK.EQ.0.0) GO TO 107
      AETSNO=0.5*PET
      IF(AETSNO.GT.PACK) GO TO 107
      PACK=PACK-AETSNO
      GO TO 203
  107 AETSNO=PACK
      PACK=0.0
      IF(TAVG.GT.32.) GO TO 108
  109 PACK=PRECIP+PACK
      RAIN=0.
      GO TO 108
  203 IF(TAVG.LE.32.) GO TO 109
      MA=0.05*(TAVG-34.)
      IF(MA.LE.0.) MA=0.
      IF(MA.GE.PACK) GO TO 110
      MR=PRECIP*(TAVG-20.)/144.
      M=MA+MR
      IF(M.GE.PACK) GO TO 110
      PACK=PACK-M
      RAIN=PRECIP+M
      GO TO 108
  110 M=PACK
      PACK=0.0
      RAIN=M+PRECIP
C   **********************************************
C   *                                            *
```

```
C  *          EVALUATION OF SOIL MOISTURE          *
C  *                     AND                       *
C  *  CALCULATION OF ACTURAL EVAPOTRANSPIRATION    *
C  *                                               *
C  *************************************************
  108 DO 1007 AREA=1,2
       AR=AREA
      FDAY(AR)=FDAY(AR)+1
      IF (FDAY(AR).LT.366.) GO TO 111
      REFF(AR)=((802.-FDAY(AR))/802.)*0.55+0.24
      GO TO 204
  111 REFF(AR)=((365.-FDAY(AR))/365.)*0.02+0.79
  204 SMUZ=SM(1,1,AREA)
      IF (RAIN.LE.0.0) GO TO 112
C  ****************************************************
C  *                                                  *
C  *  CALCULATE SURFACE RUNOFF VOLUME BY SCS METHOD   *
C  *                                                  *
C  ****************************************************
      RCL(SOIL,CROP)=RCN(SOIL,CROP)
      IF (FDAY(AR).LT.548) GO TO 113
      RCL(SOIL,CROP)=RCN(SOIL,CROP)*(1+0.05*(FDAY(AR)-548)/
     1               (802-548))
  113 IF( SMUZ.LT.0.6*FCU(1)) GO TO 114
      IF( SMUZ.GT.0.9*FCU(1)) GO TO 115
      GO TO 205
  114 RCM(SOIL,CROP)=RCL(SOIL,CROP)*0.39*EXP(0.009*RCL(SOIL,CROP))
      GO TO 206
  115 RCM(SOIL,CROP)=RCL(SOIL,CROP)*1.95*EXP(-0.00663*
     1               RCL(SOIL,CROP))
      GO TO 206
  205 RCM(SOIL,CROP)=RCL(SOIL,CROP)
  206 IF(ICROP.EQ.3) RCM(SOIL,CROP)=RCM(SOIL,CROP)*1.05
      SI=1000.0/RCM(SOIL,CROP)-10.0
      ER=RAIN-0.2*SI
      IF(ER.LT.0.0) GO TO 116
      RNOF=ER**2/(RAIN+0.8*SI)
      GO TO 207
  112 RNOF=0.0
C  *********************************
C  *                               *
C  *  CALCULATE INTERCEPTION LOSSES *
C  *                               *
C  *********************************
      IA=0.0
      GO TO 208
  116 RNOF=0.0
  207 IA=0.1
      IF(IA.GT.RAIN) IA=RAIN
      IF ((IA+RNOF).GT.RAIN) RNOF=RAIN-IA
      IF((IA+IAADD(AR)).GE.0.1) IA=0.1-IAADD(AR)
      IF (IA.LE.0.0) IA=0.0
  208 IAET=IA+IAADD(AR)
      POND(AR)=RNOF*WSERAT
```

```
      IF(AREA.EQ.1) GO TO 117
      RAIN=RAIN+PCND(1)
      RNOF=0.0
  117 PERC=RAIN-RNOF-IA
      UZEVAP=0.0
C   ***********************************************************
C   *                                                         *
C   *  CALCULATE EVAPORATION FROM BARE SOIL SURFACE (UZEVAP)  *
C   *                                                         *
C   ***********************************************************
      AETUZ=0.0
      K=1
      TAU=EXP(-0.398*LAIC(AR))
      UL2=FCU(1)-U(SOIL)
      IF(SMUZ.LE.UL2+0.01) GO TO 118
C   **************************************
C   *                                    *
C   *  CALCULATE STAGE 1 SOIL EVAPORATION *
C   *                                    *
C   **************************************
      UZEVP1=PET*(TAU/ALPH)*(1.-REFF(AR))
      EVAPMX=SMUZ-(FCU(1)-U(SOIL))
      IF(EVAPMX.LT.0.0) EVAPMX=0.0
      IF(UZEVP1.GT.EVAPMX) UZEVP1=EVAPMX
      UZEVAP=UZEVP1
      T(AR)=0
      GO TO 209
C   **************************************
C   *                                    *
C   *  CALCULATE STAGE 2 SOIL EVAPORATION *
C   *                                    *
C   **************************************
  118 T(AR)=T(AR)+1
      UZEVP2=(CC(SOIL)*(T(AR)**0.5)-CC(SOIL)*((T(AR)-1)**0.5))*
     1TAU/ALPH+UZEVAP
      UZEVAP=UZEVP2
  209 IF(UZEVAP.GT.(PET-IAET)) UZEVAP=PET-IAET
      IF(UZEVAP.LT.0.0) UZEVAP=0.0
      IF(SMUZ.LE.(0.5*PWP(K))) UZEVAP=0.0
      IAADD(AR)=IAET-PET
      IF (IAADD(AR).LT.0.0) IAADD(AR)=0.0
      K=1
      L=1
      LAI=0.0
      TRANS=0.0
      TRANSM=0.0
      LAIC(AR)=LAI
      DO 1008 K=1,16
      AVISM(K)=SM(K,L,AREA)-PWP(K)
      AVLFC(K)=FCU(K)-PWP(K)
      IF(AVLSM(K).LT.0.0) AVLSM(K)=0.0
      TRANSP(K)=0.0
      IF(PERC.LE.0.0) SM(K,5,AREA)=SM(K,1,AREA)
 1008 CONTINUE
```

```
      K=1
      L=1
      AETUZ=UZEVAP+TRANSP(1) C
C    ****************************************
C    *                                      *
C    *  DISTRIBUTION OF WATER ADDED TO AREA *
C    *                                      *
C    ****************************************
      IF (PERC.LE.0.0) PERC=0.0
      INFIL(K)=PERC
  119 SMAVL(K)=FCU(K)-SM(K,L,AREA)
      IF(SMAVL(K).LT.0.0) SMAVL(K)=0.0
      EXTRA(K)=INFIL(K)-SMAVL(K)
      IF(EXTRA(K).LT.0.0) EXTRA(K)=0.0
      SM(K,L,AREA)=SM(K,L,AREA)+INFIL(K)-EXTRA(K)
      INFIL(K+1)=EXTRA(K)
      K=K+1
      IF(K.LE.16.AND.INFIL(K).GT.0.0) GO TO 119
      RCHGR=INFIL(K)
      DO 1009 K=1,16
      DO 1010 L=1,6
      SMP(K,L,AREA)=SM(K,L,AREA)/12.
      IF(K.LE.2) SMP(K,L,AREA)=SM(K,L,AREA)/6.
      IF(SMP(K,L,AREA).GT.1.) SMP(K,L,AREA)=1.
 1010 CONTINUE
 1009 CONTINUE
      K=1
      L=1
      DTIME=0.1667
      IF(PERC.LE.0.0) DTIME=1.0
      IF(PERC.LE.0.0) L=5
C    *************************************************
C    *                                               *
C    *  CALCULATE UNSATURATED HYDRAULIC CONDUCTIVITY *
C    *                                               *
C    *************************************************
      DO 1011 K=1,16
      XYZ=SMP(K,L,AREA)*D(K)+C(K)
      H(K)=EXP(XYZ)*1013.
      IF(H(K).GT.15000) H(K)=15000
      IF(H(K).LT.0.0) H(K)=0.0
      GO TO (120,121,122,122,123,124,125,126,126,126,126,126,126,
     1 126,126,127),K
  120 COND(K)=KSAT*EXP(32.6*SMP(K,L,AR)/SAT(K)-32.6)
      GO TO 210
  121 COND(K)=KSAT*EXP(46.66*SMP(K,L,AR)/SAT(K)-46.66)
      GO TO 210
  122 COND(K)=KSAT*EXP(31.54*SMP(K,L,AR)/SAT(K)-31.54)
      GO TO 210
  123 COND(K)=KSAT*EXP(29.537*SMP(K,L,AR)/SAT(K)-29.537)
      GO TO 210
  124 COND(K)=KSAT*EXP(29.185*SMP(K,L,AR)/SAT(K)-29.185)
      GO TO 210
  125 COND(K)=KSAT*EXP(28.619*SMP(K,L,AR)/SAT(K)-28.619)
```

```
      GO TO 210
  126 COND(K)=KSAT*EXP(33.351*SMP(K,I,AR)/SAT(K)-33.351)
      GO TO 210
  127 COND(K)=KSAT*EXP(34.996*SMP(K,I,AR)/SAT(K)-34.996)
  210 IF(COND(K).GT.10.0) COND(K)=10.0
 1011 IF(COND(K).LT.1.0E-06) COND(K)=1.0E-06
C  ********************************************************************
C  *                                                                  *
C  *  CALCULATE FLOW BETWEEN ADJACENT SOIL LAYERS USING DARCY LAW     *
C  *                                                                  *
C  ********************************************************************
  129 DO 1012 K=1,15
      Q(K)=(COND(K)+COND(K+1))/2*DTIME*(H(K+1)-(H(K)-LEN(K)))/LEN(K)
C *** Q IS FLOW IN CM PER TIME PERIOD. H IS SOIL MOISTURE TENSION
C *** IN CM. DELTA Z=30.48 CM. COND(K) IS UNSATURATED HYDRAULIC
C *** CONDUCTIVITY IN CM PER DAY.
      Q(K)=Q(K)/2.54
      IF(Q(K).GE.0.0) GO TO 128
C  *******************
C  *                 *
C  *  WATER FLOWS UP *
C  *                 *
C  *******************
      SM(K,L,AREA)=SM(K,L,AREA)-Q(K)
      SM(K+1,L,AREA)=SM(K+1,L,AREA)+Q(K)
      GO TO 1012
C  *********************
C  *                   *
C  *  WATER FLOWS DOWN *
C  *                   *
C  *********************
  128 SM(K,L,AREA)=SM(K,L,AREA)-Q(K)
      SM(K+1,L,AREA)=SM(K+1,L,AREA)+Q(K)
 1012 CONTINUE
      DO 1013 K=1,16
 1013 SM(K,L+1,AREA)=SM(K,L,AREA)
      RCHG=Q(15)
      RCHGS=RCHGS+RCHG
      L=L+1
      K=1
      IF(L.LT.6) GO TO 129
      DPERC=RCHGS+RCHGR
      SM(1,6,AREA)=SM(1,6,AREA)-UZEVAP-TRANSP(K)
      DO 1014 K=2,15
      SM(K,6,AREA)=SM(K,6,AREA)-TRANSP(K)
 1014 CONTINUE
      DO 1015 K=1,15
      SMP(K,6,AREA)=SM(K,6,AREA)/12.
      IF (K.LE.2) SMP(K,6,AREA)= SM(K,6,AREA)/6.
 1015 CONTINUE
      WRITE (6,63) NM,ND,YEAR,(SMP(K,6,AREA),K=1,15)
   63 FORMAT( 6X,I2,' / ',I2,' / ',I2,3X,15F7.3)
      DO 1016 K=1,15
      AETTOT=AETTOT+TRANSP(K)
```

```
 1016 SMOIST=SMOIST+SM(K,6,AREA)
      IF(AREA.EQ.2) GO TO 130
      WSACCT(NM,2)=WSACCT(NM,2)+PRECIP*2.54
      WSACCT(NM,3)=WSACCT(NM,3)+IA*2.54
      WSACCT(NM,4)=WSACCT(NM,4)+RNOF*2.54
      WSACCT(NM,5)=WSACCT(NM,5)+DPERC*2.54
      WSACCT(NM,6)=WSACCT(NM,6)+(AETTOT+AETSNO+UZEVAP)*2.54
      WSACCT(NM,7)=WSACCT(NM,7)+(SMOIST-SMPD1)*2.54
      SMPD1=SMOIST
      GO TO 211
  130 BEACCT(NM,2)=BEACCT(NM,2)+PRECIP*2.54
      BEACCT(NM,3)=BEACCT(NM,3)+PCND(1)*2.54
      BEACCT(NM,4)=BEACCT(NM,4)+IA*2.54
      BEACCT(NM,5)=BEACCT(NM,5)+DPERC*2.54
      BEACCT(NM,6)=BEACCT(NM,6)+(AETTOT+AETSNO+UZEVAP)*2.54
      BEACCT(NM,7)=BEACCT(NM,7)+(SMOIST-SMPD2)*2.54
      SMPD2=SMOIST
  211 RCHG=0.0
      RCHGR=0.0
      RCHGS=0.0
      DO 1017 K=1,15
      INFIL(K)=0.0
      TRANSP(K)=0.0
      Q(K)=0.0
 1017 SM(K,1,AREA)=SM(K,6,AREA)
      INFIL(16)=0.0
      SM(16,1,AREA)=SM(16,6,AREA)
      SMOIST=0.0
      AETTOT=0.0
 1007 CONTINUE
      WRITE (6,64)
   64 FORMAT (3X)
      NDAY=NDAY+1
      PCND(1)=0.0
      POND(2)=0.0
 1005 CONTINUE
C                 ------------------
C                 |                |
C          ***** | EXIT DAILY LOOP | *****
C                 |                |
C                 ------------------
      WSACCT(NM,1)=AMONTH(NM)
      WSACCT(NM,8)=PACK*2.54
      DO 1018 J=2,7
 1018 WSACCT(13,J)=WSACCT(13,J)+WSACCT(NM,J)
      WSACCT(13,1)=AMONTH(13)
      WSACCT(13,8)=PACK*2.54
      BEACCT(NM,1)=AMONTH(NM)
      BEACCT(NM,8)=PACK*2.54
      DO 1019 J=2,7
 1019 BEACCT(13,J)=BEACCT(13,J)+BEACCT(NM,J)
      BEACCT(13,1)=AMONTH(13)
      BEACCT(13,8)=PACK*2.54
 1004 CONTINUE
```

```
C              --------------------
C              |                  |
C        ***** | EXIT MONTHLY LOOP | *****
C              |                  |
C              --------------------
      WRITE(6,65)
   65 FORMAT('1',46X,'***** ANNUAL SUMMARY *****')
      WRITE(6,66) YEAR
   66 FORMAT('0',35X,'WATER BALANCE (IN CM) IN THE WATERSHED AREA -'
     1,' 19',I2/10X,'--------------------------------------------------'
     2,'--------------------------------------------------------------'
     3,'---------'/24X,'INPUTS',38X,'OUTPUTS'/21X,'-------------',2X
     4'          -------------------------------------------'
     5,'--------'/9X'MONTH',7X,'PRECIPITATION',17X,'INTERCEPTION',2X
     6'SURFACE RUNOFF',3X,'PERCOLATION',8X,'AET',8X,'CHANGE IN SM',
     74X,'PACK')
      WRITE(6,67)  ((WSACCT(I,K),K=1,8),I=1,13)
   67 FORMAT( 10X,A4,F15.2,15X,5F15.2,F13.2)
      WRITE(6,68)  KROP
   68 FORMAT('0',10X,'ICROP=',I2)
      WRITE(6,69)  YEAR
   69 FORMAT('0',35X,'WATER BALANCE (IN CM) IN THE BENCH AREA - 19',
     1I2/10X,'----------------------------------------------------'
     2,'--------------------------------------------------------------'
     3,'--'/32X,'INPUTS',38X,'OUTPUTS'/21X,'----------------------'
     4,'----- ',1X,' -----------------------------------------------'
     5,'------'/9X,'MONTH',7X,'PRECIPITATION',2X,'RUNOFF APPLIED',1X
     6,'INTERCEPTION',19X,'PERCOLATION',8X,'AET',8X,'CHANGE IN SM',
     74X,'PACK')
      PACKIN=PACK
      PACK=PACK*2.54
      DSNOW=PACK-PACKPY
      WRITE(6,70)  ((BEACCT(I,K),K=1,8),I=1,13)
   70 FORMAT(10X,A4,3F15.2,15X,3F15.2,F13.2)
      WRITE(6,68)  KROP
      WRITE(6,71)  PACK,DSNOW,WSBRAT
   71 FORMAT('0',10X,'PACK ON DECEMBER 31 =',F5.2,14X,
     1'CHANGE IN SNOW STORAGE =',F5.2,14X,'WATERSHED:BENCH AREA'
     2,' RATIO=',I1,':1')
      PACKPY=PACK
      PACK=PACKIN
      WRITE (6,72)
   72 FORMAT ('0',10X,'ICROP CODE : 1 = WHEAT PLANTING YEAR'/' ',23X
     1,'2 = WHEAT HARVEST YEAR'/' ',23X,'3 = SORGHUM FALLOW YEAR'/24
     2X,'4 = SORGHUM CROP YEAR'/24X,'5 = CONTINUOUS GRAIN SORGHUM'/
     3' ',23X,'6 = CONTINUOUS WHEAT'/24X,'7 = DOUBLE FALLOWS')
 1001 CONTINUE
C              -------------------
C              |                 |
C        ***** | EXIT YEARLY LOOP | *****
C              |                 |
C              -------------------
      STOP
      END
```

***** ANNUAL SUMMARY *****

WATER BALANCE (IN CM) IN THE WATERSHED AREA - 1979

MONTH	INPUTS: PRECIPITATION	OUTPUTS: INTERCEPTION	OUTPUTS: SURFACE RUNOFF	OUTPUTS: PERCOLATION	AET	CHANGE IN SM	PACK
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AUG.	6.78	2.01	0.35	0.00	1.62	2.80	0.0
SEPT	0.13	0.13	0.0	0.00	1.99	-2.00	0.0
OCT.	3.51	0.67	0.0	0.00	0.92	1.91	0.0
NOV.	2.21	0.25	0.09	0.00	0.13	0.67	1.07
DEC.	2.29	0.69	0.14	0.00	0.06	1.77	0.69
TOT.	14.91	3.76	0.58	0.00	4.73	5.15	0.69

ICROP= 7

WATER BALANCE (IN CM) IN THE BENCH AREA - 1979

MONTH	INPUTS: PRECIPITATION	INPUTS: RUNOFF APPLIED	OUTPUTS: INTERCEPTION	OUTPUTS: PERCOLATION	AET	CHANGE IN SM	PACK
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AUG.	6.78	1.40	2.01	0.00	1.62	4.55	0.0
SEPT	0.13	0.0	0.13	0.00	2.09	-2.10	0.0
OCT.	3.51	0.0	0.67	0.00	0.92	1.91	0.0
NOV.	2.21	0.35	0.25	0.00	0.13	1.10	1.07
DEC.	2.29	0.57	0.69	0.00	0.06	2.43	0.69
TOT.	14.91	2.31	3.77	0.00	4.73	8.04	0.69

ICROP= 7

PACK ON DECEMBER 31 = 0.69 CHANGE IN SNOW STORAGE = 0.69 WATERSHED:BENCH AREA RATIO=4:1

ICROP CODE : 1 = WHEAT PLANTING YEAR
2 = WHEAT HARVEST YEAR
3 = SORGHUM FALLOW YEAR
4 = SORGHUM CROP YEAR
5 = CONTINUOUS GRAIN SORGHUM
6 = CONTINUOUS WHEAT
7 = DOUBLE FALLOWS

***** ANNUAL SUMMARY *****

WATER BALANCE (IN CM) IN THE WATERSHED AREA - 1980

MONTH	INPUTS: PRECIPITATION	OUTPUTS: INTERCEPTION	SURFACE RUNOFF	PERCOLATION	AET	CHANGE IN SM	PACK
JAN.	2.11	0.65	0.00	0.00	0.07	0.68	1.40
FEB.	1.73	0.85	0.10	0.00	0.10	2.97	0.0
MAR.	6.15	1.04	1.31	0.00	0.49	3.13	0.18
APR.	3.45	0.93	0.46	0.00	1.08	1.11	0.0
MAY	5.31	1.26	0.39	0.00	1.06	2.69	0.0
JUNE	3.71	1.07	0.00	0.00	2.67	-0.03	0.0
JULY	6.07	2.13	0.25	0.00	3.18	0.53	0.0
AUG.	5.11	1.25	0.17	0.00	2.81	0.88	0.0
SEPT	3.00	0.76	0.0	0.00	1.99	0.24	0.0
OCT.	1.83	0.27	0.0	0.00	0.92	0.64	0.0
NOV.	0.15	0.08	0.0	0.00	1.16	-1.09	0.0
DEC.	0.10	0.09	0.0	0.00	0.48	-0.46	0.0
TOT.	38.71	10.42	2.59	0.00	16.01	10.35	0.0

ICROP= 7

WATER BALANCE (IN CM) IN THE BENCH AREA - 1980

MONTH	INPUTS: PRECIPITATION	RUNOFF APPLIED	OUTPUTS: INTERCEPTION	PERCOLATION	AET	CHANGE IN SM	PACK
JAN.	2.11	0.00	0.65	0.00	0.07	0.68	1.40
FEB.	1.73	0.41	0.85	0.00	0.10	2.56	0.0
MAR.	6.15	5.24	1.04	0.00	0.49	9.68	0.18
APR.	3.45	1.35	0.93	0.00	1.08	3.41	0.0
MAY	5.31	1.19	1.26	0.00	1.06	4.18	0.0
JUNE	3.71	1.01	1.07	0.00	2.67	-0.02	0.0
JULY	6.07	1.31	2.13	0.00	3.18	1.77	0.0
AUG.	5.11	0.67	1.25	0.00	2.81	1.71	0.0
SEPT	3.00	0.0	0.76	0.00	1.99	0.24	0.0
OCT.	1.83	0.0	0.27	0.00	0.92	0.64	0.0
NOV.	0.15	0.0	0.08	0.00	1.16	-1.09	0.0
DEC.	0.10	0.0	0.09	0.00	0.48	-0.46	0.0
TOT.	38.71	10.37	10.42	0.00	16.01	23.32	0.0

ICROP= 7

PACK ON DECEMBER 31 = 0.0   CHANGE IN SNOW STORAGE =-1.40   WATERSHED:BENCH AREA RATIO=4:1

ICROP CODE : 1 = WHEAT PLANTING YEAR
2 = WHEAT HARVEST YEAR
3 = SORGHUM FALLOW YEAR
4 = SORGHUM CROP YEAR
5 = CONTINUOUS GRAIN SORGHUM
6 = CONTINUOUS WHEAT
7 = DOUBLE FALLOWS

***** ANNUAL SUMMARY *****

WATER BALANCE (IN CM) IN THE WATERSHED AREA - 1981

MONTH	INPUTS: PRECIPITATION	OUTPUTS: INTERCEPTION	SURFACE RUNOFF	PERCOLATION	AET	CHANGE IN SM	PACK
JAN.	1.75	0.38	0.0	0.00	0.27	-0.06	1.17
FEB.	0.76	0.43	0.0	0.00	0.67	0.83	0.0
MAR.	8.59	1.48	0.70	0.00	1.14	5.26	0.0
APR.	8.89	0.64	2.48	0.00	2.80	2.97	0.0
MAY	22.29	1.73	6.10	0.00	1.98	12.38	0.0
JUNE	0.38	0.38	0.0	0.00	2.41	-2.42	0.0
JULY	4.52	1.59	0.03	0.00	1.34	1.56	0.0
AUG.	3.66	1.32	0.0	0.00	3.39	-1.05	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOT.	59.75	7.95	9.31	0.00	14.00	19.47	0.0

ICROP= 7

WATER BALANCE (IN CM) IN THE BENCH AREA - 1981

MONTH	INPUTS: PRECIPITATION	RUNOFF APPLIED	OUTPUTS: INTERCEPTION	PERCOLATION	AET	CHANGE IN SM	PACK
JAN.	1.75	0.0	0.39	0.00	0.27	-0.06	1.17
FEB.	0.76	0.0	0.42	0.00	0.67	0.83	0.0
MAR.	8.59	2.79	1.48	0.00	1.14	8.75	0.0
APR.	8.89	9.92	0.64	10.12	2.80	1.76	0.0
MAY	22.29	24.42	1.73	42.26	1.98	0.64	0.0
JUNE	0.38	0.0	0.38	0.00	2.41	-2.42	0.0
JULY	4.52	0.12	1.59	0.00	1.34	1.71	0.0
AUG.	3.66	0.0	1.32	0.00	3.54	-1.20	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOT.	59.75	37.25	7.95	52.38	14.15	10.01	0.0

ICROP= 7

PACK ON DECEMBER 31 = 0.0 CHANGE IN SNOW STORAGE = 0.0 WATERSHED:BENCH AREA RATIO=4:1

ICROP CODE : 1 = WHEAT PLANTING YEAR
2 = WHEAT HARVEST YEAR
3 = SORGHUM FALLOW YEAR
4 = SORGHUM CROP YEAR
5 = CONTINUOUS GRAIN SORGHUM
6 = CONTINUOUS WHEAT
7 = DOUBLE FALLOWS

APPENDIX D

PROGRAM LISTING : LONG-TERM MODEL

```
C  ***********************************************************************
C  *                                                                     *
C  *  1.         THIS DECK WAS RECREATED AND MODIFIED                    *
C  *                 BY CHUCHING WANG --- 10-16-81                       *
C  *     SMMOD1 H. NEIBLING, KANSAS STATE UNIVERSITY, JUNE 1976.         *
C  *                                                                     *
C  *  2. THIS  PROGRAM  MODELS  SOIL  MOISTURE  DISTRIBUTION  AND        *
C  *     MOVEMANT WITHIN TOP 427 CM (14 FT) OF THE SOIL PROFILE.         *
C  *     EVAPORATION, RUNOFF, INTERCEPTION FROM THE SOIL SURFACE,        *
C  *  3. PLANT ROOT WATER EXTRACTION PATTERNS  AND  SOIL MOISTURE        *
C  *     MOVEMENT  BETWEEN  ADJACENT  SOIL  LAYERS  DECIDE  THE          *
C  *     DISTRIBUTION OF RAINFALL AND THE WATER STORAGE  IN  EACH        *
C  *     SOIL LAYER.                                                     *
C  *  4. THE PROFILE  IS  DIVIDED INTO A 15.24 CM SURFACE  LAYER,        *
C  *     A 15.24 CM LAYER IMMEDIATELY BELOW IT,  AND 14 - 30.5 CM        *
C  *     LOWER DEPTH LAYERS.                                             *
C  *  5. 182.9 CM IS TREATED AS THE BOUNDARY  BETWEEN  THE ACTIVE        *
C  *     ROOT ZONE AND THE GROUND WATER ZONE.                            *
C  *                                                                     *
C  ***********************************************************************
      INTEGER PDAY(2)
      INTEGER NDIM(12),ROTAT1,ROTAT2,T(2)
      INTEGER YSTART,YEND,YEARS,YEAR,PDAYS,PDAYW,HDAYS,HDAYW,WSBRAT
      INTEGER DAY(2),SOIL,CROP,ROTATE,AREA,AR
      REAL IA,IAET,IAADD,EO,MA,MR,M,LAI,KC(7,12),INFIL(17),LEN(16)
      REAL KSAT,SAT(16)
      REAL LAIC(2),KS(16)
      DIMENSION AVLFC(16),AVLSM(16),IAADD(2)
      DIMENSION PSUNS(12),RHD(12),RA(12),WIND(12),ERACCT(13,8)
      DIMENSION PREC(31),TMAX(31),TMIN(31),TAVG(31),AMONTH(13)
      DIMENSION TRANSP(16),SM(16,6,2),SMP(16,6,2),EXTRA(15),
     1          SMAVI(15)
      DIMENSION SMSAT(15),Q(15),H(16),CCND(16),RCN(12,7),RCM(12,7)
      DIMENSION NOCROP(2),POND(2),NCNM(2),NCND(2),NCYEAR(2)
      DIMENSION           U(12),CC(12),FCU(16),PWP(16),WSACCT(13,8)
      DIMENSION ROOT(16),C(16),D(16),KROP(70,2),REFF(2)
      DIMENSION RCI(12,7)
C  **********************************
C  *                                *
C  *  INITIALIZATION OF VARIABLES   *
C  *                                *
C  **********************************
      DATA LAIC/2*0.0/
      DATA LEN/2*15.24,14*30.48/
      DATA PERC,DPERC,RCHG,RCHGR,RCHGS/5*0.0/
      DATA IA,IAET,IAADD,LAI,AETTOT,SMOIST,PDT/7*0.0,37.5/
      DATA PACK,MA,MR,M,PACKPY/5*0.0/
      DATA DAY,SOIL/2*0,3/
      DATA CCND,H,POND/16*0.005,16*1500.0,2*0.0/
```

```
      DATA INFIL,TRANSP,ROOT,EXTRA/64*0.0/
      DATA NDIM/31,28,31,30,31,30,31,31,30,31,30,31/
      DATA AMONTH/'JAN.','FEB.','MAR.','APR.','MAY ','JUNE','JULY',
     1'AUG.','SEPT','OCT.','NOV.','DEC.','TOT.'/
      DATA U/0.47,0.47,0.39,0.39,0.39,0.39,0.35,0.35,0.31,0.31,0.28,
     10.24/
      DATA CC/0.2,0.2,0.177,0.177,0.177,0.177,0.159,0.159,0.138,
     10.138,0.134,0.131/
      DATA FCU/1.78,1.94,3.86,3.6,3.1,11*3.0/
      DATA PWP /0.59,1.21,2*1.2,0.76,0.82,0.57,8*1.21,1.27/
      DATA C /4.647,9.366,4.346,3.687,4.346,11*3.388/
      DATA D /-19.713,-33.042,-16.416,-15.465,-16.416,11*-14.303/
      DATA SM/1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3          1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3          1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3          1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3          1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62,
     3          1.59,1.46,2.33,1.73,1.63,1.72,1.87,1.97,1.98,1.97,
     12.02,1.79,1.75,1.70,1.67,1.62,1.59,1.46,2.33,1.73,1.63,1.72,
     21.87,1.97,1.98,1.97,2.02,1.79,1.75,1.70,1.67,1.62/
      DATA SMPD1,SMPD2/2*27.18/
      DATA KSAT,SAT/10.00,0.4695,0.4235,2*0.5453,0.5362,0.62,0.5589,
     1               5*0.4569,0.4446,0.4424,0.4426,0.3987/
      DATA BEACCT,WSACCT/208*0.0/
      DATA INDA,INDB,INDC,FDAY/7,1,2,2*173/
      NAMELIST/ALPHA/CROP,PDAYS,HDAYS,PDAYW,HDAYW,MSTART,YSTART,YEND
      NAMELIST/BETA/ALPH,ROTAT1,ROTAT2,WSERAT                           C
********************
C  *                   *
C  *  READ INPUT DATA  *
C  *                   *
C  *********************
      READ(5,1)   ((RCN(I,K),K=1,7),I=1,12)
    1 FORMAT(7(F2.0,1X))
      READ(5,2)   ((KC(I,K),K=1,12),I=1,7)
    2 FORMAT( 12(F3.2,1X))
      READ(5,3)   (PSUNS(I),RHD(I),RA(I),WIND(I),I=1,12)
    3 FORMAT(2X,F2.2,F2.0,F4.2,F3.1)
      READ(5,ALPHA)
      WRITE(6,ALPHA)
      READ(5,BETA)
      WRITE(6,BETA)
      XYZ=0.0
      YEARS=YEND-YSTART+1
```

```
C   ******************************
C   *                            *
C   *   ESTABLISH CROP ROTATIONS  *
C   *                            *
C   ******************************
C
C *** CROP CODE: 1=ALFALFA, 2=CORN, 3=GRAIN SORGHUM, 4=WHEAT,
C ***              5=PASTURE, 6=SOYBEANS, 7=FALLOW
C
C *** CROP ROTATION CODE: 1=CONT.G.S., 2=CONT. WHEAT, 3=G.S.-FALLOW,
C ***                       4=WHEAT-FALLOW,5=WHEAT-DOUBLE FALLOW
C
C *** AREA VALUES ARE: 1=WATERSHED,2=BENCH AREA
C
      DO 1001 LL=1,2
      ROTATE=ROTAT1
      IF(LL.EQ.2) ROTATE=ROTAT2
      GO TO (101,102,103,104,105),ROTATE
C   TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
C   T                             T
C   T   CONTINUORS GRAIN OSRGHUM  T
C   T                             T
C   TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
  101 DO 1002 K=1,YEARS
 1002 KROP(K,LL)=5
      GO TO 1001
C   TTTTTTTTTTTTTTTTTTTTTTTT
C   T                      T
C   T   CONTINUOUS WHEAT   T
C   T                      T
C   TTTTTTTTTTTTTTTTTTTTTTTT
  102 DO 1003 K=1,YEARS
 1003 KROP(K,LL)=6
      GO TO 1001
C   TTTTTTTTTTTTTTTTTTTTTTTTTTT
C   T                         T
C   T   GRAIN SORGHUM-FALLOW  T
C   T                         T
C   TTTTTTTTTTTTTTTTTTTTTTTTTTT
  103 DO 1004 K=1,YEARS,2
 1004 KROP(K,LL)=3
      DO 1005 K=2,YEARS,2
 1005 KROP(K,LL)=4
      GO TO 1001
C   TTTTTTTTTTTTTTTTTTT
C   T                 T
C   T   WHEAT-FALLOW  T
C   T                 T
C   TTTTTTTTTTTTTTTTTTT
  104 DO 1006 K=1,YEARS,2
 1006 KROP(K,LL)=1
      DO 1007 K=2,YEARS,2
 1007 KROP(K,LL)=2
      GO TO 1001
```

```
C  TTTTTTTTTTTTTTTTTTTTTTTTT
C  T                       T
C  T  WHEAT-DOUBLE FALLOW  T
C  T                       T
C  TTTTTTTTTTTTTTTTTTTTTTTTT
  105 DO 1008 K=1,YEARS,3
 1008 KROP(K,LL)=INDA
       DO 1009 K=2,YEARS,3
 1009 KROP(K,LL)=INDE
      DO 1010 K=3,YEARS,3
 1010 KROP(K,LL)=INDC
 1001 CONTINUE
C                --------------------
C                |                  |
C          ***** | ENTER YEARLY LOOP | *****
C                |                  |
C                --------------------
      DO 1011 NY=1,YEARS
      DO 1012 I=1,13
      DO 1013 J=1,8
      WSACCT(I,J)=0.0
 1013 BEACCT(I,J)=0.0
 1012 CONTINUE
      IF(NY.GT.1) MSTART=1
      NDAY=0
      NOCROP(1)=0
      NOCROP(2)=0
      WRITE (6,61)
   61 FORMAT('1',46X,'***** ANNUAL SUMMARY *****')
C                ---------------------
C                |                   |
C          ***** | ENTER MONHTLY LOOP | *****
C                |                   |
C                ---------------------
      DO 1014 NM=MSTART,12
  106 READ (1,4,END=5000) KAN,STIND,YEAR,MONTH,(PREC(I),I=1,31),
     1(TMAX(I),I=1,31),(TMIN(I),I=1,31)
    4 FORMAT( I2,I4,2I2,31F4.2,62F3.0)
      IF(YEAR.LT.YSTART) GO TO 106
      IF (YEAR.GT.YEND) GO TO 5000
      IF(MONTH.LT.MSTART.AND.YEAR.EQ.YSTART) GO TO 106
      R=0.23
      NDIM(2)=28
      IF(NM.EQ.2.AND.TMAX(29).LT.900) NDIM(2)=29
      NDAYS=NDIM(NM)
C                -------------------
C                |                 |
C          ***** | ENTER DAILY LOOP | *****
C                |                 |
C                -------------------
      DO 1015 ND=1,NDAYS
C  ***********************************************************
C  *                                                         *
C  *  CALCULATION OF POTENTIAL EVAPOTRANSPIRATION ( PET )    *
```

```
C   *                       BY  MEANS  OF                            *
C   *                PENMAN  COMBINATION  EQUATION                   *
C   *                                                                *
C   ******************************************************************
        TMAX(ND)=TMAX(ND)-100.
        TMIN(ND)=TMIN(ND)-100.
C***    TAVG IS THE AVERAGE DAILY AIR TEMPERATURE, DEGREE FAHRENHEIT
        TAVG(ND)=(TMAX(ND)+TMIN(ND))/2.0
C ***   FOLLOWING STATEMENTS CORRECT FOR MISSING DATA ON INPUT TAPE
        IF(TAVG(ND).GT.800) TAVG(ND)=PDT
        IF(PREC(ND).GT.99.97) PREC(ND)=0.0
C ***   THE NEXT TWO CARDS CONVERT TAVG TO ABSOLUTE, DEGREE KELVIN
        CENT=(TAVG(ND)-32.0)*100.0/180.0
        ABST=CENT+273.16
C ***   ES IS THE DAILY CALCULATED SATURATED VAPOR PRESSURE, IN MB
        ES=33.9*((0.00738*CENT+0.8072)**8-0.000019*ABS(1.8*CENT+48)
       1 +0.00136)
C ***   ESA IS THE DAILY CALCULATED ACTUAL VAPOR PRESSURE, IN MB
        ESA=ES*RHD(NM)/100.0
C ***   RN IS THE CALCULATED DAILY NET RADIATION, IN MM OF WATER
        RN=(1-R)*RA(NM)*(0.22+0.54*PSUNS(NM))-2.010E-09*ABST**4*
       1(0.98-0.77-0.027*SQRT(ESA))*(0.1+0.9*PSUNS(NM))
C ***   WINDD IS THE MONTHLY AVERAGE WINDRAN, MILES/DAY AT 2 M HEIGHT
        WINDD=(WIND(NM)*24)*0.555
C ***   ES IS THE DAILY CALCULATED SATURATED VAPOR PRESSURE, IN MB
        EA=0.35*(0.5+0.01*WINDD)*(ES-ESA)
        IF(TAVG(ND)) 107,107,108
  107   DELTA=0.0
        GO TO 201
  108   DELTA=0.039*TAVG(ND)**0.673
  201   GAMMA=1-DELTA
        PET=((DELTA*RN)+(GAMMA*EA))/25.39998
C ***   PET IS THE CALCULATED DAILY POTENTIAL EVAPOTRANSPIRATION, INCH
        PDT=TAVG(ND)
        IF(TAVG(ND).LT.20.0) PET=0.0
        IF(PET.LT.0.0) PET=0.0
        AADD=IAADD(1)
        IF(PET-AADD) 109,109,110
  109   AADD=AADD-PET
        IF(AADD.LT.0.0) AADD=0.0
        PET=0.0
        GO TO 202
  110   PET=PET-AADD
  202   DO 1016 AR=1,2
        IAADD(AR)=AADD
 1016   CONTINUE
C   ************************************************************
C   *                                                          *
C   *  CALCULATION OF MOISTURE ADDED DUE TO SNOWMELT           *
C   *                                                          *
C   ************************************************************
        M=0.0
        AETCNO=0.0
        PRECIP=PREC(ND)
```

```
      RAIN=PRECIP
      TRANST=0.0
      IF(PACK.EQ.0.0) GO TO 111
      AETSNO=0.5*PET
      IF(AETSNO.GT.PACK) GO TO 111
      PACK=PACK-AETSNO
      GO TO 203
  111 AETSNO=PACK
      PACK=0.0
      IF (TAVG(ND).GT.32.) GO TO 112
  113 PACK=PRECIP+PACK
      RAIN=0.
      GO TO 112
  203 IF (TAVG(ND).LE.32.) GO TO 113
      MA=0.05*(TAVG(ND)-34.)
      IF(MA.LE.0.) MA=0.
      IF(MA.GE.PACK) GO TO 114
      MR=PRECIP*(TAVG(ND)-20.)/144.
      M=MA+MR
      IF(M.GE.PACK) GO TO 114
      PACK=PACK-M
      RAIN=PRECIP+M
      GO TO 112
  114 M=PACK
      PACK=0.0
      RAIN=M+PRECIP
C    ************************************************
C    *                                              *
C    *         EVALUATION OF SOIL MOISTURE          *
C    *                     AND                      *
C    *  CALCULATION OF ACTURAL EVAPOTRANSPIRATION   *
C    *                                              *
C    ************************************************
  112 DO 1017 AREA=1,2
      AR=AREA
C    ************************************************************
C    *                                                          *
C    *  DETERMINATION OF CROP GROWN ON EACH AREA EACH YEAR      *
C    *                                                          *
C    ************************************************************
      ROTATE=ROTAT1
      IF(AREA.EQ.2) ROTATE=ROTAT2
      GO TO (115,116,117,117,118),ROTATE
C    TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
C    T                               T
C    T  CONTINUORS GRAIN OSRGHUM     T
C    T                               T
C    TTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTTT
  115 CROP=3
      IF(NDAY.GT.PDAYS.AND.NDAY.LT.HDAYS) GO TO 119
      CROP=7
      DAY(AR)=0
      FDAY(AR)=FDAY(AR)+1
      REFF(AR)=((252.-FDAY(AR))/252.)*0.29+0.08
```

```
      GO TO 119
C   TTTTTTTTTTTTTTTTTTTTTTT
C   T                     T
C   T   CONTINUOUS WHEAT  T
C   T                     T
C   TTTTTTTTTTTTTTTTTTTTTTT
  116 CROP=4
      IF(NDAY.LT.HDAYW.OR.NDAY.GT.PDAYW) GO TO 119
      CROP=7
      FDAY(AR)=FDAY(AR)+1
      REFF(AR)=((092.-FDAY(AR))/092.)*0.36+0.22
      DAY(AR)=0
      GO TO 119
  117 ICROP=KROP(NY,AREA)
C
C *** ICROP CODE: 1=WHEAT PLANTING,2=WHEAT HARVEST,
C ***             3=SORGHUM FALLOW YEAR, 4=SORGHUM CROP YEAR
C
      GO TO (120,121,122,123), ICROP
C   TTTTTTTTTTTTTTTTTTT
C   T                 T
C   T   WHEAT-FALLOW  T
C   T                 T
C   TTTTTTTTTTTTTTTTTTT
  120 CROP=4
      IF(NDAY.GE.PDAYW) GO TO 119
      CROP=7
      DAY(AR)=0
      FDAY(AR)=FDAY(AR)+1
      REFF(AR)=((458.-FDAY(AR))/458.)*0.46+0.22
      GO TO 119
  121 CROP=4
      IF(NDAY.LT.HDAYW) GO TO 119
      CROP=7
      DAY(AR)=0
      FDAY(AR)=FDAY(AR)+1
      REFF(AR)=((458.-FDAY(AR))/458.)*0.46+0.22
      GO TO 119
C   TTTTTTTTTTTTTTTTTTTTTTTTTTT
C   T                         T
C   T   GRAIN SORGHUM-FALLOW  T
C   T                         T
C   TTTTTTTTTTTTTTTTTTTTTTTTTTT
  122 CROP=7
      DAY(AR)=0
      FDAY(AR)=FDAY(AR)+1
      REFF(AR)=((616.-FDAY(AR))/616.)*0.40+0.08
      GO TO 119
  123 CROP=3
      IF(NDAY.GT.PDAYS.AND.NDAY.LT.HDAYS) GO TO 119
      CROP=7
      DAY(AR)=0
      FDAY(AR)=FDAY(AR)+1
      REFF(AR)=((616.-FDAY(AR))/616.)*0.40+0.08
```

```
      GO TO 119
C  TTTTTTTTTTTTTTTTTTTTTTTTT
C  T                       T
C  T  WHEAT-DOUBLE FALLOW  T
C  T                       T
C  TTTTTTTTTTTTTTTTTTTTTTTTT
  118 IF(KROP(NY,AR).NE.7) GO TO 124
       CROP=7
      DAY(AR)=0
      FDAY(AR)=FDAY(AR)+1
  204 IF (FDAY(AR).LT.366.) GO TO 125
      REFF(AR)=((802.-FDAY(AR))/802.)*0.55+0.24
      GO TO 119
  125 REFF(AR)=((365.-FDAY(AR))/365.)*0.02+0.79
      GO TO 119
  124 IF (KRCP(NY,AR).EQ.2) GO TO 126
       CROP=4
      IF (NDAY.GE.FDAYW) GO TO 119
       CROP=7
      DAY(AR)=0
      FDAY(AR)=FDAY(AR)+1
      GO TO 204
  126 IF (NDAY.LT.HDAYW) GO TO 119
       CROP=7
      DAY(AR)=0
      FDAY(AR)=FDAY(AR)+1
      GO TO 204
  119 SMUZ=SM(1,1,AREA)
      IF(DAY(AR).NE.0) FDAY(AR)=0
      IF(DAY(AR).NE.0) REFF(AR)=0.
      IF (RAIN.LE.0.0) GO TO 127
C  **************************************************
C  *                                                *
C  *  CALCULATE SURFACE RUNOFF VOLUME BY SCS METHOD *
C  *                                                *
C  **************************************************
      RCL(SOIL,CROP)=RCN(SOIL,CROP)
      IF (FDAY(AR).LT.548) GO TO 128
      RCL(SOIL,CROP)=RCN(SOIL,CROP)*(1+0.05*(FDAY(AR)-548)/
     1               (802-548))
  128 IF( SMUZ.LT.0.7*FCU(1)) GO TO 129
      IF( SMUZ.GE.1.0*FCU(1)) GO TO 130
      GO TO 205
  129 RCM(SOIL,CROP)=RCL(SOIL,CROP)*0.39*EXP(0.009*RCL(SOIL,CROP))
      GO TO 206
  130 RCM(SOIL,CROP)=RCL(SOIL,CROP)*1.95*EXP(-0.00663*
     1               RCL(SOIL,CROP))
      GO TO 206
  205 RCM(SOIL,CROP)=RCL(SOIL,CROP)
  206 IF(ICROP.EQ.3) RCM(SOIL,CROP)=RCM(SOIL,CROP)*1.05
      SI=1000.0/RCM(SOIL,CROP)-10.0
      ER=RAIN-0.2*SI
      IF(ER.LT.0.0) GO TO 131
      RNOF=ER**2/(RAIN+0.8*SI)
```

```
      GO TO 207
  127 RNOF=0.0
C   ***********************************
C   *                                 *
C   *  CALCULATE INTERCEPTION LOSSES  *
C   *                                 *
C   ***********************************
      IA=0.0
      GO TO 208
  131 RNOF=0.0
  207 IA=0.1
      IF(IA.GT.RAIN) IA=RAIN
      IF ((IA+RNOF).GT.RAIN) RNOF=RAIN-IA
      IF((IA+IAADD(AR)).GE.0.1) IA=0.1-IAADD(AR)
      IF (IA.LE.0.0) IA=0.0
  208 IAET=IA+IAADD(AR)
      POND(AR)=RNOF*WSERAT
      IF(AREA.EQ.1) GO TO 132
      RAIN=RAIN+POND(1)
      RNOF=0.0
  132 PERC=RAIN-RNOF-IA
      UZEVAP=0.0
C   *********************************************************
C   *                                                       *
C   *  CALCULATE EVAPORATION FROM BARE SOIL SURFACE (UZEVAP) *
C   *                                                       *
C   *********************************************************
      AETUZ=0.0
      K=1
      TAU=EXP(-0.398*LAIC(AR))
      UL2=FCU(1)-U(SOIL)
C   ****************************************
C   *                                      *
C   *  CALCULATE STAGE 1 SOIL EVAPORATION  *
C   *                                      *
C   ****************************************
      UZEVP1=PET*(TAU/ALPH)*(1.-REFF(AR))
      EVAPMX=SMUZ-(FCU(1)-U(SOIL))
      IF(EVAPMX.LT.0.0) EVAPMX=0.0
      IF(UZEVP1.GT.EVAPMX) UZEVP1=EVAPMX
      IF ( SMUZ.GT.UL2+0.01 ) GO TO 133
C   ****************************************
C   *                                      *
C   *  CALCULATE STAGE 2 SOIL EVAPORATION  *
C   *                                      *
C   ****************************************
      T(AR)=T(AR)+1
      UZEVAP=(CC(SOIL)*(T(AR)**0.5)-CC(SOIL)*((T(AR)-1)**0.5))*
     1       TAU/ALPH+UZEVAP
      IF ( UZEVP2.GT.UZEVP1 ) GO TO 133
      UZEVAP=UZEVP2
      GO TO 209
  133 T(AR)=0
      UZEVAP=UZEVP1
```

```
  209 IF(UZEVAP.GT.(PET-IAET)) UZEVAP=PET-IAET
      IF(UZEVAP.LT.0.0) UZEVAP=0.0
      IF(SMUZ.LE.(0.5*PWP(K))) UZEVAP=0.0
      IAADD(AR)=IAET-PET
      IF  (IAADD(AR).LT.0.0) IAADD(AR)=0.0
      IF(DAY(AR).LE.0) GO TO 134
      IF(CROP.EQ.7) GO TO 134
      IF(CROP.EQ.4) GO TO 135
      GO TO 210
C  ***********************************
C  *                                 *
C  *  WHEAT LEAF AREA INDEX FUNCTION *
C  *                                 *
C  ***********************************
  135 IF(DAY(AR).LT.3) LAI=0.0
      IF(DAY(AR).GE.3.AND.DAY(AR).LT.37) LAI=0.0106*(DAY(AR)-3)
      IF(DAY(AR).GE.37.AND.DAY(AR).LT.53)LAI=0.36-8.125E-03*
     1                                   (DAY(AR)-37)
      IF(DAY(AR).GE.53.AND.DAY(AR).LT.153) LAI=0.23-1.5E-03*
     1                                      (DAY(AR)-53)
      IF(DAY(AR).GE.153.AND.DAY(AR).LT.189)LAI=0.08+0.0144*
     1                                      (DAY(AR)-153)
      IF(DAY(AR).GE.189.AND.DAY(AR).LT.199) LAI=0.60+0.022*
     1                                      (DAY(AR)-189)
      IF(DAY(AR).GE.199.AND.DAY(AR).LT.217) LAI=0.82-0.028*
     1                                       (DAY(AR)-199)
      IF(DAY(AR).GE.217.AND.DAY(AR).LT.239) LAI=0.31-0.014*
     1                                       (DAY(AR)-217)
      IF(DAY(AR).GE.239) LAI=0.0
      GO TO 211
C  *************************************
C  *                                   *
C  *  SORGHUM LEAF AREA INDEX FUNCTION *
C  *                                   *
C  *************************************
  210 IF(DAY(AR).GE.0.AND.DAY(AR).LT.29) LAI=0.006571*DAY(AR)
      IF(DAY(AR).GE.29.AND.DAY(AR).LT.35) LAI=0.23+0.09*(DAY(AR)-29)
      IF(DAY(AR).GE.35.AND.DAY(AR).LT.42) LAI=0.77+0.19*(DAY(AR)-35)
      IF(DAY(AR).GE.42.AND.DAY(AR).LT.49) LAI=2.10+0.286*
     1                                    (DAY(AR)-42)
      IF(DAY(AR).GE.49.AND.DAY(AR).LT.56)LAI=4.10+0.119*(DAY(AR)-49)
      IF(DAY(AR).GE.56.AND.DAY(AR).LT.77) LAI=4.93-0.0928*
     1                                    (DAY(AR)-56)
      IF(DAY(AR).GE.77.AND.DAY(AR).LT.115) LAI=2.57-0.0142*
     1                                     (DAY(AR)-77)
      IF(DAY(AR).GE.115) LAI=0.00
  211 TRANS=PET-UZEVAP
      K=1
      L=1
      TRANS=TRANS*KC(CROP,NM)
      IF(CROP.EQ.3) GO TO 136
C  **********************************
C  *                                *
C  *  WHEAT ROOT EXTRACTION PATTERN *
```

```
C   *                                   *
C   *************************************
      K=1
      ROOT(K)=(72.0-0.104*(DAY(AR)-55))/100.
      IF(DAY(AR).GE.0.AND.DAY(AR).LT.55)ROOT(K)=(100.-0.509*DAY(AR))
     1/100.
      K=2
      ROOT(K)=(20.0-0.0469*DAY(AR))/100.
      IF(DAY(AR).GE.0.AND.DAY(AR).LT.55) ROOT(K)=(0.363*DAY(AR))/100
      K=3
      ROOT(K)=0.145*DAY(AR)/100
      IF(DAY(AR).GE.55) ROOT(K)=0.08+(0.0448*(DAY(AR)-55))/100
      K=4
      ROOT(K)=0.0
      IF(DAY(AR).GE.189) ROOT(K)=0.09
      K=5
      ROOT(K)=0.0
      IF(DAY(AR).GE.193) ROOT(K)=0.08
      K=6
      ROOT(K)=0.0
      IF(DAY(AR).GE.218) ROOT(K)=0.03
      K=7
      ROOT(K)=0.0
      GO TO 212
C   *************************************
C   *                                   *
C   *  SORGHUM ROOT EXTRACTION PATTERN  *
C   *                                   *
C   *************************************
  136 K=1
      ROOT(K)=(56.0-0.391*DAY(AR))/100.
      IF(DAY(AR).GE.0.AND.DAY(AR).LT.61) ROOT(K)=(100.0-1.466
     1*DAY(AR))/100.
      K=2
      ROOT(K)=(23.0-0.174*DAY(AR))/100.
      IF(DAY(AR).GE.0.AND.DAY(AR).LT.61) ROOT(K)=(0.766*DAY(AR))/100
      K=3
      ROOT(K)=0.334*DAY(AR)/100
      IF(DAY(AR).GE.61.AND.DAY(AR).LT.63) ROOT(K)=0.21
      IF(DAY(AR).GE.63.AND.DAY(AR).LT.73) ROOT(K)=(21.0-1.1*
     1(DAY(AR)-63))/100
      IF(DAY(AR).GE.73)  ROOT(K)=0.19
      K=4
      ROOT(K)=0.0
      IF(DAY(AR).GE.73) ROOT(K)=0.13
      K=5
      ROOT(K)=0.0
      IF(DAY(AR).GE.104) ROOT(K)=0.10
      K=6
      ROOT(K)=0.0
      IF(DAY(AR).GE.104.AND.DAY(AR).LT.119) ROOT(K)=0.05
      IF(DAY(AR).GE.119) ROOT(K)=0.10
      K=7
      ROOT(K)=0.0
```

```
      IF(DAY(AR).GE.130) ROOT(K)=0.05
      GO TO 212
  134 K=1
      L=1
      LAI=0.0
      TRANS=0.0
  212 TRANSM=0.0
      LAIC(AR)=LAI
      DO 1018 K=1,16
      KS(K)=1.0
      AVLFC(K)=FCU(K)-PWP(K)
      AVLSM(K)=SM(K,1,AREA)-PWP(K)
      IF(AVLSM(K).LT.0.0) AVLSM(K)=0.0
      IF(AVLSM(K).LT.0.3*AVLFC(K)) KS(K)=AVLSM(K)/(0.3*AVLFC(K))
      IF(K.LT.2) GO TO 137
      IF(ROOT(K).LE.0.) GO TO 137
      IF(KS(K-1).LT.1.) ROOT(K)=ROOT(K)+(ROOT(K-1)*(1.-KS(K-1)))
  137 TRANSP(K)=TRANS*KS(K)*ROOT(K)
      IF(SM(K,1,AREA).LE.PWP(K)) TRANSP(K)=0.0
      IF(PERC.LE.0.0) SM(K,5,AREA)=SM(K,1,AREA)
 1018 CONTINUE
      K=1
      L=1
      AETUZ=UZEVAP+TRANSP(1)
C   ****************************************
C   *                                      *
C   *  DISTRIBUTION OF WATER ADDED TO AREA *
C   *                                      *
C   ****************************************
      IF (PERC.LE.0.0) PERC=0.0
      INFIL(K)=PERC
  138 SMAVL(K)=FCU(K)-SM(K,L,AREA)
      IF(SMAVL(K).LT.0.0) SMAVL(K)=0.0
      EXTRA(K)=INFIL(K)-SMAVL(K)
      IF(EXTRA(K).LT.0.0) EXTRA(K)=0.0
      SM(K,L,AREA)=SM(K,L,AREA)+INFIL(K)-EXTRA(K)
      INFIL(K+1)=EXTRA(K)
      K=K+1
      IF(K.LE.16.AND.INFIL(K).GT.0.0) GO TO 138
      RCEGR=INFIL(K)
      DO 1019 K=1,16
      DO 1020 L=1,6
      SMP(K,L,AREA)=SM(K,L,AREA)/12.
      IF(K.LE.2) SMP(K,L,AREA)=SM(K,L,AREA)/6.
      IF(SMP(K,L,AREA).GT.1.) SMP(K,L,AREA)=1.
 1020 CONTINUE
 1019 CONTINUE
      K=1
      L=1
      DTIME=0.1667
      IF(PERC.LE.0.0) DTIME=1.0
      IF(PERC.LE.0.0) L=5
C   **************************************************
C   *                                                *
```

```
C   *  CALCULATE UNSATURATED HYDRAULIC CONDUCTIVITY  *
C   *                                                *
C   **************************************************
      DO 1021 K=1,16
      XYZ=SMP(K,L,AREA)*D(K)+C(K)
      H(K)=EXP(XYZ)*1013
      IF(H(K).GT.15000) H(K)=15000
      IF(H(K).LT.0.0) H(K)=0.0
      GO TO (139,140,141,141,142,143,144,145,145,145,145,145,145,
     1 145,145,146),K
  139 COND(K)=KSAT*EXP(32.6*SMP(K,L,AR)/SAT(K)-32.6)
      GO TO 213
  140 COND(K)=KSAT*EXP(46.66*SMP(K,L,AR)/SAT(K)-46.66)
      GO TO 213
  141 COND(K)=KSAT*EXP(31.54*SMP(K,L,AR)/SAT(K)-31.54)
      GO TO 213
  142 COND(K)=KSAT*EXP(29.537*SMP(K,L,AR)/SAT(K)-29.537)
      GO TO 213
  143 COND(K)=KSAT*EXP(29.185*SMP(K,L,AR)/SAT(K)-29.185)
      GO TO 213
  144 COND(K)=KSAT*EXP(28.619*SMP(K,L,AR)/SAT(K)-28.619)
      GO TO 213
  145 COND(K)=KSAT*EXP(33.351*SMP(K,L,AR)/SAT(K)-33.351)
      GO TO 213
  146 COND(K)=KSAT*EXP(34.996*SMP(K,L,AR)/SAT(K)-34.996)
  213 IF(COND(K).GT.10.0) COND(K)=10.0
 1021 IF(COND(K).LT.1.0E-04) COND(K)=1.0E-04
C   *************************************************************
C   *                                                           *
C   *  CALCULATE FLOW BETWEEN ADJACENT SOIL LAYERS USING DARCY LAW  *
C   *                                                           *
C   *************************************************************
  148 DO 1022 K=1,15
      Q(K)=(COND(K)+COND(K+1))/2*DTIME*(H(K+1)-(H(K)-LEN(K)))/LEN(K)
C *** Q IS FLOW IN CM PER TIME PERIOD. H IS SOIL MOISTURE TENSION
C *** IN CM. DELTA Z=30.48 CM. COND(K) IS UNSATURATED HYDRAULIC
C *** CONDUCTIVITY IN CM PER DAY.
      Q(K)=Q(K)/2.54
      IF(Q(K).GE.0.0) GO TO 147
C   *******************
C   *                 *
C   *  WATER FLOWS UP *
C   *                 *
C   *******************
      SM(K,L,AREA)=SM(K,L,AREA)-Q(K)
      SM(K+1,L,AREA)=SM(K+1,L,AREA)+Q(K)
      GO TO 1022
C   *********************
C   *                   *
C   *  WATER FLOWS DOWN *
C   *                   *
C   *********************
  147 SM(K,L,AREA)=SM(K,L,AREA)-Q(K)
      SM(K+1,L,AREA)=SM(K+1,L,AREA)+Q(K)
```

```
1022 CONTINUE
     DO 1023 K=1,16
1023 SM(K,L+1,AREA)=SM(K,L,AREA)
     RCHG=Q(15)
     RCHGS=RCHGS+RCHG
     L=I+1
     K=1
     IF(L.LT.6) GO TO 148
     DPERC=RCHGS+RCHGR
     SM(1,6,AREA)=SM(1,6,AREA)-UZEVAP-TRANSP(K)
     DO 1024 K=2,15
     SM(K,6,AREA)=SM(K,6,AREA)-TRANSP(K)
1024 CONTINUE
     DO 1025 K=1,15
     AETTOT=AETTOT+TRANSP(K)
1025 SMOIST=SMOIST+SM(K,1,AREA)
     IF(NOCROP(AR).GT.0) GO TO 149
     IF(SMOIST.LE.13.41.AND.DAY(AR).GT.0) NOCROP(AR)=1
     NCNM(AR)=NM
     NCND(AR)=ND
     NCYEAR(AR)=YEAR
 149 IF(AREA.EQ.2) GO TO 150
     WSACCT(NM,2)=WSACCT(NM,2)+PRECIP*2.54
     WSACCT(NM,3)=WSACCT(NM,3)+IA*2.54
     WSACCT(NM,4)=WSACCT(NM,4)+RNOF*2.54
     WSACCT(NM,5)=WSACCT(NM,5)+DPERC*2.54
     WSACCT(NM,6)=WSACCT(NM,6)+(AETTOT+AETSNO+UZEVAP)*2.54
     WSACCT(NM,7)=WSACCT(NM,7)+(SMOIST-SMPD1)*2.54
     SMPD1=SMOIST
     GO TO 214
 150 BEACCT(NM,2)=BEACCT(NM,2)+PRECIP*2.54
     BEACCT(NM,3)=BEACCT(NM,3)+POND(1)*2.54
     BEACCT(NM,4)=BEACCT(NM,4)+IA*2.54
     BEACCT(NM,5)=BEACCT(NM,5)+DPERC*2.54
     BEACCT(NM,6)=BEACCT(NM,6)+(AETTOT+AETSNO+UZEVAP)*2.54
     BEACCT(NM,7)=BEACCT(NM,7)+(SMOIST-SMPD2)*2.54
     SMPD2=SMOIST
 214 RCHG=0.0
     RCHGR=0.0
     RCHGS=0.0
     DO 1026 K=1,15
     INFIL(K)=0.0
     TRANSP(K)=0.0
     Q(K)=0.0
1026 SM(K,1,AREA)=SM(K,6,AREA)
     INFIL(16)=0.0
     SM(16,1,AREA)=SM(16,6,AREA)
     SMOIST=0.0
     AETTOT=0.0
     DAY(AR)=DAY(AR)+1
1017 CONTINUE
     NDAY=NDAY+1
     POND(1)=0.0
     POND(2)=0.0
```

```
 1015 CCNTINUE
C               ------------------
C               |                |
C         ***** | EXIT DAILY LOOP | *****
C               |                |
C               ------------------
      WSACCT(NM,1)=AMONTH(NM)
      WSACCT(NM,8)=PACK*2.54
      DO 1027 J=2,7
 1027 WSACCT(13,J)=WSACCT(13,J)+WSACCT(NM,J)
      WSACCT(13,1)=AMONTH(13)
      WSACCT(13,8)=PACK*2.54
      BEACCT(NM,1)=AMONTH(NM)
      BEACCT(NM,8)=PACK*2.54
      DC 1028 J=2,7
 1028 BEACCT(13,J)=BEACCT(13,J)+BEACCT(NM,J)
      BEACCT(13,1)=AMONTH(13)
      BEACCT(13,8)=PACK*2.54
 1014 CONTINUE
C               --------------------
C               |                  |
C         ***** | EXIT MONTHLY LOOP | *****
C               |                  |
C               --------------------
      WRITE(6,62 ) YEAB
   62 FORMAT('0',35X,'WATER BALANCE (IN CM) IN THE WATERSHED AREA -'
     1,' 19',I2/10X,'-----------------------------------------------
     2,'-------------------------------------------------------------'
     3,'---------'/24X,'INPUTS',38X,'OUTPUTS'/21X,'-------------',2X
     4'           -----------------------------------------------'
     5,'--------'/9X'MONTH',7X,'PRECIPITATION',17X,'INTERCEPTION',2X
     6'SURFACE RUNOFF',3X,'PERCOLATICN',8X,'AET',8X,'CHANGE IN SM',
     74X,'PACK')
      WRITE(6,63)  ((WSACCT(I,K),K=1,8),I=1,13)
   63 FORMAT( 10X,A4,F15.2,15X,5F15.2,F13.2)
      WRITE(6,64 ) KROP(NY,1)
   64 FORMAT('0',10X,'ICROP=',I2)
      WRITE(6,65 ) YEAB
   65 FORMAT('0',35X,'WATER BALANCE (IN CM) IN THE BENCH AREA - 19',
     1I2/10X,'------------------------------------------------------'
     2,'-------------------------------------------------------------'
     3,'--'/32X,'INPUTS',38X,'OUTPUTS'/21X,'----------------------'
     4,'----- ',1X,' ----------------------------------------------'
     5,'------'/9X,'MONTH',7X,'PRECIPITATION',2X,'RUNOFF APPLIED',1X
     6,'INTERCEPTICN',19X,'PERCOLATICN',8X,'AET',8X,'CHANGE IN SM',
     74X,'PACK')
      PACKIN=PACK
      PACK=PACK*2.54
      DSNCW=PACK-PACKPY
      WRITE(6,66)  ((BEACCT(I,K),K=1,8),I=1,13)
   66 FCRMAT(10X,A4,3F15.2,15X,3F15.2,F13.2)
      WRITE(6,64 ) KROP(NY,2)
      IF(NOCROP(2).EQ.1) WRITE(6,67 ) NCNM(2),NCND(2),NCYEAR(2)
   67 FORMAT('0UNKNCWN DATE IS:  ',I2,'/',I2,'/',I2)
```

```
      WRITE(6,68 ) PACK,DSNOW,WSBRAT
   68 FORMAT('0',10X,'PACK ON DECEMBER 31 =',F5.2,14X,
     1'CHANGE IN SNOW STORAGE =',F5.2,14X,'WATERSHED:BENCH AREA'
     2,' RATIO=',I1,':1')
      PACKPY=PACK
      PACK=PACKIN
      WRITE (6,69 )
   69 FORMAT ('0',10X,'ICROP CODE : 1 = WHEAT PLANTING YEAR'/' ',23X
     1,'2 = WHEAT HARVEST YEAR'/' ',23X,'3 = SORGHUM FALLOW YEAR'/24
     2X,'4 = SORGHUM CROP YEAR'/24X,'5 = CONTINUOUS GRAIN SORGHUM'/
     3' ',23X,'6 = CONTINUOUS WHEAT'/24X,'7 = DOUBLE FALLOWS')
 1011 CONTINUE
C                  --------------------
C                  |                  |
C           *****  | EXIT YEARLY LOOP |  *****
C                  |                  |
C                  --------------------
 5000 STOP
      END
```

APPENDIX E

SUMMARY OF LONG-TERM MODEL RESULTS

WATER BALANCE (IN CM) IN THE WATERSHED AREA

	INPUTS		OUTPUTS					
YEAR	PRECIP	SNOW MELT	INTER-CEPTION	RUNOFF	DEEP PERC	ACTUAL ET	SNOW PACK	CHANGE IN SM
1920	70.89	0.00	14.92	6.50	0.16	37.35	1.90	10.04
1921	50.65	1.90	9.49	6.10	0.10	15.76	0.00	21.18
1922	48.11	0.00	7.89	8.27	1.33	16.96	0.00	11.07
1923	69.93	0.00	16.36	4.29	0.03	52.22	0.00	- 3.02
1924	42.80	0.00	10.42	1.65	7.02	16.42	2.45	4.82
1925	36.80	2.45	10.86	1.65	7.67	23.03	0.00	- 3.94
1926	29.11	0.00	10.82	0.05	0.02	39.60	0.00	-21.42
1927	47.78	0.00	13.93	1.62	0.01	18.08	0.25	13.87
1928	54.31	0.25	11.85	4.50	9.24	21.98	0.00	7.00
1929	50.65	0.00	14.20	0.84	0.01	49.53	0.00	-13.96
1930	64.95	0.00	10.09	9.24	10.97	17.04	0.00	17.50
1931	40.84	0.00	9.35	2.98	9.45	21.24	0.89	- 3.05
1932	38.33	0.89	11.26	0.41	0.01	47.82	0.28	-20.61
1933	46.08	0.28	10.43	4.89	0.01	12.49	0.00	18.52
1934	21.84	0.00	9.32	0.59	0.01	16.56	0.00	- 4.62
1935	33.60	0.00	9.31	0.27	0.01	40.74	0.00	-16.75
1936	30.63	0.00	8.95	2.65	0.01	10.15	0.36	8.49
1937	37.90	0.36	10.37	1.76	0.01	23.58	0.00	2.55
1938	46.79	0.00	10.31	1.50	0.00	48.56	0.00	-13.64
1939	39.07	0.00	8.65	3.01	0.00	14.32	2.35	10.71
1940	39.65	2.35	11.40	2.95	0.00	22.18	0.00	5.48
1941	77.98	0.00	14.38	13.42	0.01	53.02	2.52	- 5.40
1942	53.59	2.52	10.95	7.06	3.45	15.73	0.00	18.91
1943	35.18	0.00	8.83	3.57	7.86	20.34	0.00	- 5.41
1944	73.76	0.00	13.15	8.57	1.03	45.52	0.00	5.46
1945	50.83	0.00	8.89	4.92	23.00	14.55	0.00	- 0.57
1946	71.42	0.00	10.22	13.00	27.20	21.25	0.08	- 0.34
1947	42.57	0.08	12.49	0.68	0.01	46.76	0.15	-17.46
1948	51.69	0.15	11.74	2.57	2.27	17.72	0.38	17.15
1949	69.34	0.38	13.11	10.50	22.50	27.63	0.00	- 4.02
1950	40.77	0.00	12.12	1.38	0.01	41.22	0.00	-14.01
1951	59.05	0.00	11.83	6.99	9.15	12.92	0.00	18.14
1952	35.31	0.00	10.81	3.76	3.72	21.41	0.00	- 4.39
1953	50.11	0.00	13.24	2.73	0.01	43.39	0.12	- 9.42
1954	31.65	0.12	8.65	2.01	0.01	13.43	0.76	6.89
1955	28.47	0.76	9.27	0.36	0.01	19.99	0.00	- 0.39

WATER BALANCE (IN CM) IN THE WATERSHED AREA

	INPUTS		OUTPUTS					
YEAR	PRECIP	SNOW MELT	INTER-CEPTION	RUNOFF	DEEP PERC	ACTUAL ET	SNOW PACK	CHANGE IN SM
1956	22.05	0.00	8.60	0.00	0.01	33.24	0.00	-19.84
1957	73.41	0.00	13.62	10.68	3.52	18.09	0.05	27.43
1958	57.58	0.05	10.35	10.27	18.45	22.26	0.00	- 3.70
1959	43.03	0.00	11.76	0.79	0.00	44.74	0.00	-14.29
1960	55.60	0.00	12.95	5.53	1.80	16.10	0.71	18.52
1961	47.02	0.71	10.79	4.31	15.18	20.46	0.00	- 3.05
1962	63.83	0.00	11.27	5.36	0.00	52.88	0.00	- 5.72
1963	45.31	0.00	8.96	6.63	7.06	14.30	0.00	8.38
1964	30.56	0.00	7.48	3.52	7.13	18.03	0.00	- 5.63
1965	69.67	0.00	12.94	6.45	0.00	47.21	0.00	3.02
1966	36.42	0.00	8.11	2.35	10.02	12.33	0.76	2.83
1967	28.37	0.76	10.92	0.79	1.81	20.43	0.39	- 5.22
1968	48.29	0.39	10.43	5.60	0.00	41.96	1.74	-11.07
1969	44.07	1.74	11.53	2.05	0.00	18.57	0.03	13.60
1970	43.54	0.03	8.89	6.10	9.38	19.79	0.00	- 0.58
1971	45.39	0.00	11.96	0.67	0.00	49.60	0.00	-16.87
1972	46.28	0.00	12.27	2.59	0.00	15.82	0.06	15.54
1973	64.64	0.06	9.69	10.24	19.12	23.40	0.97	1.25
1974	43.61	0.97	10.65	4.44	0.00	47.83	0.76	-19.12
1975	61.65	0.76	7.00	17.76	5.63	9.36	0.00	22.70
1976	30.12	0.00	8.34	2.41	6.03	17.59	0.00	- 4.33
1977	56.44	0.00	13.58	2.77	0.00	52.78	0.00	-12.97
1978	39.47	0.00	8.24	3.29	0.00	12.21	0.05	15.65
TOTAL	2808.81	17.96	640.19	261.84	251.43	1609.47	18.01	41.95
AVE	47.61	0.30	10.85	4.44	4.26	27.28	0.31	0.71

EFFECT OF WHEAT DOUBLE FALLOW
ON
WATER STORAGE AND DRAINAGE

by

Chuching Wang

B. S., National Taiwan University, R. O. C., 1979

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirement for the degree

MASTER OF SCIENCE

Department of Civil Engineering

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1982

ABSTRACT

Fallowing of land in western Kansas is a proven technique to increase soil moisture for subsequent crops. The typical fallow period is 15 months and, currently, about 30 percent of the precipitation that falls during the fallow period is stored in the rooting zone for subsequent use. This amount of water, however, is not enough to produce significant groundwater recharge. The developed idea presented here is to lengthen the fallow period from 15 months to 27 months, which is called double fallow, more water would be available to increase soil moisture. It could greatly increase the probability of exceeding the moisture holding capacity of soil in the rooting zone and drainage of water below the rooting zone, and ultimately to the underlying aquifer, under this condition would be possible.

The purposes of this study were to: 1. verify the concept of double fallow through a field experiment to determine the fallow efficiency and whether movement of soil water below rooting zone would result. 2. design a computer model to simulate soil moisture storage and movement. 3. design and modify a continuous water budget model to simulate conditions during wheat double fallow and use this model to assess the groundwater recharge potential. These purposes were achieved by conducting a field experiment at Colby, Kansas, to obtain the necessary soil information and daily meteorological data; calibrating a short-term water budget model with the field data;

and running a long-term continuous water budget model using the historical weather records for the period 1920 to 1978 and the same soil data measured from the field experiment.

From the results of field experiment, 34.7 percent fallow efficiency and 10.4 cm of drainage below 2.5 m were measured. The long-term model showed an average 35 percent fallow efficiency and an average of 4.3 cm of potential recharge per year. The amount of recharge would be significant if compared with almost no recharge under current fallow pratices and considerd from a long-term point of view. So, the conclusion of this research is : for better protection of groundwater resources in western Kansas, wheat-double fallow is one feasible method and should be favorably furthered.