YIELD SIMULATION MODEL FOR RICE

by

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Certificate

This is to certify that this thesis work has been done by me and neither this thesis nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

A simulation model has been developed using Stress Day Index concept which can be used to predict the effect of drought on rice yield. The model scans the stress days using daily water balance and calculates the relative yield based on experimentally determined crop susceptibility factors. The model was applied to a drought prone area to determine the optimum transplanting date of Aman rice grown under rainfed condition and best date of supplemental irrigation. Long term weather data, were collected and analysed to determine the normal weather condition of the study area. Other input data for model application were obtained from literature and judicious assumptions.

The results of the model application revealed that economically acceptable yield of Aman rice under rainfed condition could be obtained by the proper selection of transplanting date. When transplanted later supplemental irrigation was required during reproductive and ripening stage to avoid yield loss due to drought. The number of supplemental irrigation was found to be dependant on the type of soil and planting date. Land management, i.e. adjustment of dike height was found to be an effective way of reducing the number of supplemental irrigation for heavy and moderate to light textured soils. High risk of substantial yield loss is involved when Transplanted Aman is grown in light textured soils under rainfed condition.

The model could not be verified due to lack of appropriate field data. The crop susceptibility factors used in the model were experimentally determined, hence the model is expected to yield reasonable results. However, further verification of the model with appropiate field data is necessary. Nevertheless, the model can be used as an effective tool to select the planting date to maximize the effective use of rainfall and to identify the optimum schedule of supplemental irrigation.

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INTRODUCTION

Background and Problem Definition

About 20% of the total arable land in Bangladesh is now under irrigation and the rest is cultivated under rainfed condition (BBS, 1986). The land under rainfed condition is dependant on the mercy of nature and this dependance is critical in the Kharif season (April to October) during which two thirds of the food grains are produced. Annual rainfall in Bangladesh ranges from 1400mm in the northwest to over 5000mm in the northeast. But ninety percent of this rainfall occurs during the four months from June to September. Rain is scarce and highly unpredictable during the months of October to May. Therefore drought of varying intensities occur almost in all parts of Bangladesh in Rabi (November - March), early Kharif I (April - July) and late Kharif II (July - December) seasons while primary irrigation is necessary during Rabi (December - March). Crop grown under rainfed condition, suffers substantial yield loss due to drought. Aman rice is transplanted in July / August and is harvested in November / December. By October it reaches its final growth stages. As such Transplanted Aman grown under rainfed condition are affected by drought hazards.

Where water is scarce and expensive the optimum planting date for a specific crop grown under rainfed condition is to be determined. But if it so happens that economically acceptable yield level is not feasible under rainfed condition minimum amount and best date for supplimental irrigation become the determining factors for efficient crop production. Saleh (1981) had concluded that supplementary irrigation increased the yield of rice as high as 71 % over rainfed condition.

Yield simulation models have been developed and successfully applied to evaluate and improve the on-farm water management practice for wheat, corn, soybeans, peanuts, etc. (Baker and Horrocks, 1973; Hill and Hanks, 1978; Rasmussen and Hanks, 1978; Retta and Hanks, 1979; Martin, Watts, Gilley and Borcher, 1981; Pusposuturdjo, 1982; Agulto, 1984). Some research work has been conducted on the effects of water stress on rice yield (Wickham, 1971; Datta, 1972; Yoshida, 1975; Angus, 1979; Karim, 1985). Thus if a yield simulation model for rice could be developed it could be used to predict the impact of various water management options on rice yield.

Hence the present study has been designed to develop a yield simulation model for rice and to apply the model to determine the optimum planting date and best dates of supplemental irrigation for Transplanted Aman rice grown in a drought prone area of Bangladesh.

Objectives

The purpose of this study is to develop a yield simulation model for rice which can be used as an effective tool for the evaluation and improvement of water management practice.

The specific objectives are ;

1. To develop a yield simulation model for rice using Stress Day Index concept,
2. To apply the model for determining an optimum planting date for Transplanted Aman grown under rainfed condition,
3. To apply the model for determining the best date of a specified amount of supplimental irrigation and its impact on yield, and
4. To apply the model for planning the irrigation schedule to have economically acceptable level of yield.
5. To apply the model for determining the effect of dike height on effective use of rainfall and required supplemental irrigation.

REVIEW OF LITERATURE

The water requirements of crops has been a subject of much study in the past. A great deal of research information is available on the relationships between crop, climate, water and soil. Most of the water requirement studies have concentrated on climatic factors that influence water use for maximum crop production. However, for practical application in planning, design and operation of schemes, it is necessary to analyse the effect of water deficits on crop yields. Whenever the crop water requirement is not fully met, water deficits in the plant will cause reduced yield. The degree and manner in which water deficits affect crop growth and yield, varies with the crop species and growth stages.

Physiological Characteristics of Rice

Any attempt to estimate rice yield requires the study of its physiological characteristics. The yield response of rice to various environmental conditions is highly dependant on its variety, stage of growth, method of cultivation, etc.

According to Datta (1981) rice culture can be classified into four types based on varietal type. These are:

1. Lowland rice, with plants of semidwarf to medium to tall height (100cm to 200cm)
2. Upland rice, with plants of medium to tall (130cm to 150cm) height
3. Deep water rice, with plants of medium to tall (120cm to 150cm without standing water and 200cm to 300cm with rising water level) height
4. Floating rice, with tall (>150cm tall without standing water; 500cm to 600cm with rising flood water) plants.

Recently, Barker and Herdt (1979) classified rice in South and Southeast Asia, according to water depth. For lowland rainfed rice they used shallow rainfed (5 - 15cm) and medium deep rainfed (16 - 100cm), with medium deep rainfed further classified into intermediate deep (15 - 50cm) and semi-deep rainfed (51 - 100cm). Where water depths exceede 100cm they classified rice as deep water. Further refinements have been made of the system suggested by Barker and Herdt (1979), with both deep-water and floating rice areas totally excluded from the rainfed lowland rice areas. The refinement of the classification are given in Table 1.

In our country rice is classified as Aus, Aman and Boro depending on the growing season. Aus and Aman rice can be either Transplant or Broadcast type. Boro rice is usually transplanted. There are also many varieties of local and high yielding variety (HYV) rice. High yielding Variety Transplanted Aman was selected for the present study.

TABLE 1. Classification of Rice Culture (De Datta, 1981)

Types of culture	Main method of planting	Maximum water depth in cm
Rainfed low land rice	Transplanting	0 - 50
Shallow rainfed lowland rice	Transplanting	5 - 15
Medium-deep rainfed lowland rice	Transplanting	16 - 50
Deep water rice	Broadcast on to dry soil	51 - 100
Upland rice	Drilled into dry soil	No standing water

Growth stage- The entire life cycle of the rice plant may be divided into three main phases, These are;

1. The vegetative phase, which runs from germination to panicle initiation,
2. The reproductive phase, which runs from panicle initiation to flowering.
3. The ripening phase, which runs from flowering to full maturity

These main phases, however may be subdivided into physiologically distinct stages or periods, Fig, 1 shows the detailed divisions of the main phases of the rice crop with different durations, The duration of the basic vegetative stage varies among varieties generally, between 25-65 days, The reproductive phase begins with panicle initiation and lasts upto complete flowering, In ripening phase (from flowering to maturity) occupies a period from 25 to 35 days before maturity regardless of variety,

Growth stages and their respective duration as used by Karim (1985) are given in Table 2,

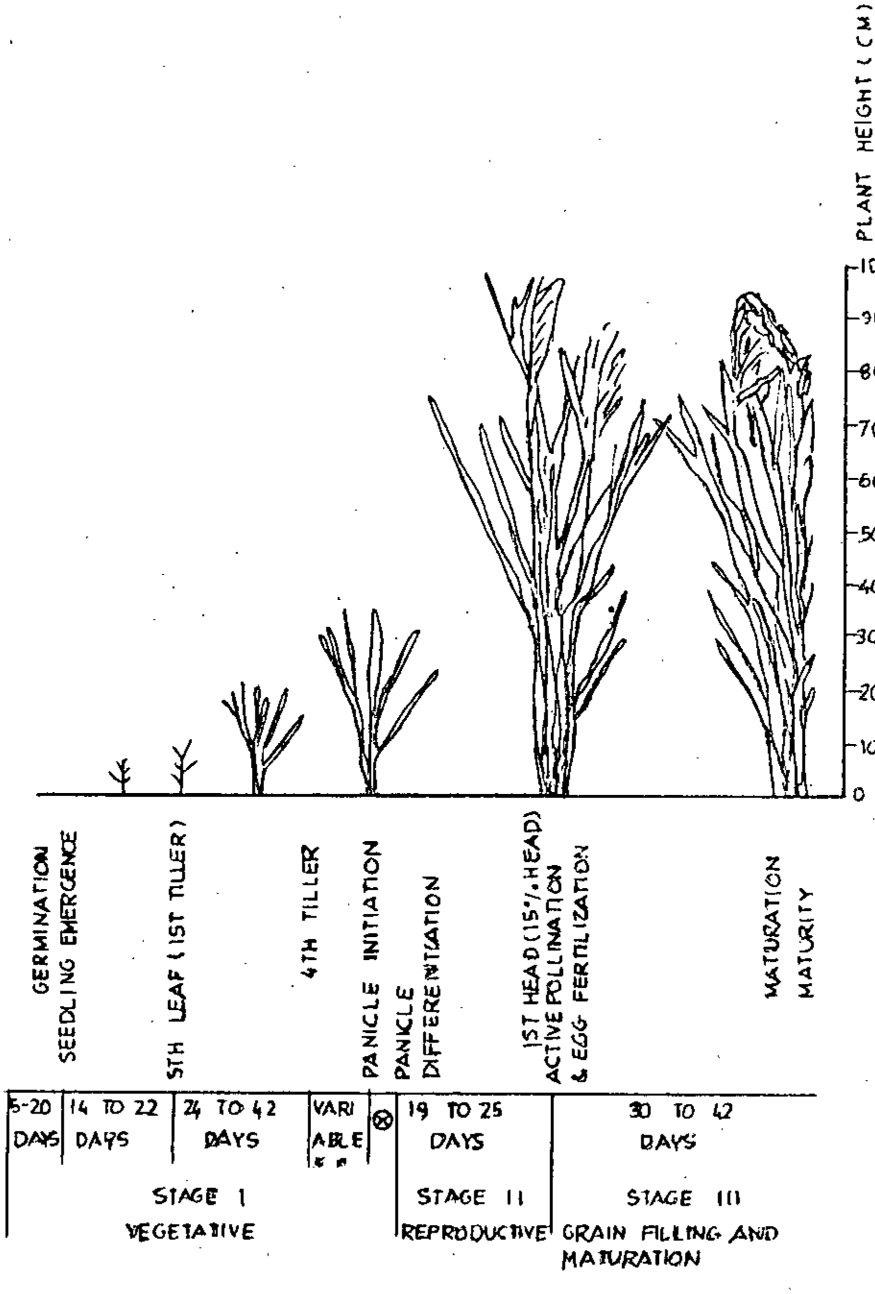


FIG. 1. -- DEVELOPMENT PHASES OF RICE PLANT (MANALO)

Table 2. Growth Stages and their Respective Duration of HYV and LIV Rice (Karim, 1985)

Crop (1)	Growth stages (2)	No. of days within growth stage (3)
HYV rice	Transpalnting - Maximum tillering	45
	Maximum tillering - Panicle initiation	5
	Panicle initiation - Heading	30
	Heading - Milk	10
	Milk - Maturity	20
Local improved varieties of rice	Gemination - Maximum tillering	50
	Maximum tillering - Heading	35
	Heading - Milk	10
	Milk - Maturity	20

On the basis of the above specification, the duration of the different growth stages of Transplanted Aman can be summarized as:

1. Vegetative phase - 50 days
2. Reproductive phase - 30 days
3. Ripening phase - 30 days

<u>Crop growing season</u>- Selection of the crop growing season or the crop calendar is very important in relation to drought damage. Crop calendar is different for different country and sometimes it varies from region to region within a country. Moreover, a particular variety of rice may be very susceptible to drought condition upto certain stage

of growth. But if the growing season of the rice is such that the timing of drought does not coincide with critical stage of growth then there may not be severe crop damage due to drought. The resistence or susceptibility to moisture stress at different stage of growth is different. The growing season of Transplanted Aman is such that critical condition for it may arise after vegetative and reproductive growth stages. The transplatation of Aman is performed during July-August and is harvested during November-December.

Dike Height

Experimental studies have concluded that farmers could make better use of scarce water supplies by providing higher dike height. It results not only in fewer stress days and higher yields, it can also reduce drainage losses and improve the irrigation efficiency of the system (Wickham, 1971). Dike is also an effective way of controlling weed (De Datta, 1981) by providing standing water depth in the field. In Bangladesh a dike height of 150 to 200mm is usually provided for rice fields.

Stress Development and Yield Reduction

Under rainfed condition the paddies often become dry and the crop suffers from various degrees of moisture stress. Moisture stress may be the chief factor that limits economical and stable yields of rainfed rice.

The moisture stress effects on rice or any other plant relates to the result from the function of water within the plant. The functions of water can be pointed out as;

1. water is a vital constituent of cell protoplasm
2. water is a reactant or reagent in chemical reactions (e.g., in photosynthesis; water + carbondioxide + energy → carbohydrates)
3. water is a solvent for organic and inorganic solutes and gases facilitating their translocation within the plant
4. water gives mechanical strength to plants by producing turgidity.

Low water supply rates and high water loss rates cause a decrease in plant water content which results in the development of plant moisture stress. Moisture stress decreases the rate of photosynthesis. Respiration rate also decreases but less rapidly than photosynthetic rates. Therefore decrease in yield in water stressed plants results bothfrom a decrease in photosynthetic rate and also an increase in the ratio of respiration to photosynthesis. Stress causes delayed flowering and high percentage of sterility, and consequently, low yield.

Internal moisture stress in rice plant tissues seems to cause poor growth in many upland rice. Early work in Japan clearly indicated that the rice plant is most sensitive to drought from the cell division stage to the flowering stage (IRRI, 1975). Three days drought around the critical time (from 11 days to 3 days before heading) reduced yield by causing high percentage of sterility.

Soil moisture tension as low as 15 centibars was found sufficient to reduce the grain yield of rainfed lowland rice (Datta, Abilay, Kalwar, 1972). In general peak water demand of rice is between maximum tillering and grain filling stage. It has been demonstrated that moisture stress imposed between transplanting and maturity reduces yield by 74% (Datta, Abilay, Kalwar, 1972). Moisture stress also increases the days of maturity of HYV rice. Moisture stress in late vegetative and reproductive stages resulted in the decrease of grain yield through a reduction in the number of spikelets.

Crop Yield-Water Relationships

Some of the earliest yield water relations were obtained by researchers investigating the effects of precipitation and soil moisture on crop yield.

Cole (1938) studied wheat yield and precipitation of 272 data points from 14 research stations in Northern Great Plains in the United States over the period 1906 - 1935 to establish a yield relation of wheat to precipitation.

De Wit (1958) collected wide range of data for common field crops grown in containers under controlled evaporation. Graphical representation of these experimental data showed that for different crops under different moisture conditions yield linearly varies with transpiration.

Arkley (1963) extended the work of De Wit by plotting the yield of dry matter versus transpiration corrected for mean relative atmospheric humidity during the period of most active growth. Arkley concluded that deviation from a straight line with increasing moisture reveals the effect of over irrigation, while reversal in the slope of a line suggests water logging and poor aeration in the soil.

Datta, Abilay and Kalwar (1972) conducted experiment on several varieties of rice to determine the moisture stress effects. It is evident from their experiment that early moisture stress during the growth of plant reduces tillering. This results in a reduction in grain yield.

Reyes (1972) attempted to explain the yield response of rice to water from three dry season experiments. The study was based on the experiments to evaluate the effects of climatic differences, varietal differences and nitrogen fertilizer on the yield response of rice to water. Several varieties were found to be effectively responding to high nitrogen levels even under conditions of poor water supply.

Recently an attempt was made (Consortium International Development, 1976) to develop methods for predicting crop yields based on experimental results for maize. The objective of developing a yield function reflecting influences on yields of different water supply levels and moisture tensions within the root zone at different stages of crop growth was achieved by plotting the experimental results as yield versus water use.

Yield Models

Yield Functions - Many attempts have been made to develop a functional relationship between yield and water inputs, taking into account the effects of water deficits at different stages of growth. Some of the earliest production functions were obtained by researchers investigating the effects of precipitation and soil moisture on dryland crop yields by regression analysis (Cole, 19389; Legget, 1959).

Moore (1961) developed a model to allow calculation of the net variable income associated with each irrigation cycle, allowing calculation of the optimal time to apply irrigation water. He used a hypothetical relationship betweeen the relative rate of plant growth and the mean soil moisture stress in the active root zone as for an entire irrigation season,

$$Gr = \sum_{i=1}^{n} I_{ei} \ (t_i/T)$$

where,

Gr = relative growth

T = length of irrigation season (days)

t_i = length of irrigation i^{th} cycle (days)

I_{ei} = fraction of potential growth for one irrigation cycle

Hall and Butcher (1968) developed a method which could be used to assure that the seasonal distribution of water was optimal for each point on the overall production function. They expressed yield as a multiplicative function as ;

$$Y = \prod_{i=1}^{n} a_i(w_i) \ Y_{max}$$

where,

Y = yield

Y_{max} = maximum yield of a crop

$a_i(w_i)$ = yield reduction factor for stress applied on i^{th} growth stage

w_i = soil moisture content in the i^{th} stage

Jensen (1968) related relative yield to the effects of limited soil moisture as :

$$Y/Y_{max} = \prod_{i=1}^{n} (E_T/E_{TP})^{\lambda_i}$$

where,

Y/Y_{max} = relative yield

$(ET/ET_{TP})_i$ = relative total evapotranspiration for growth stage, i

λ_i = relative sensitivity of the crop to water stress during growth stage, i

The right side of the equation is a product. Therefore stress developed by reduced water during a single growth stage will reduce yield severely.

Hiller and Clark (1971) developed a concept to determine the stress imposed on a crop during its growing season. The Stress Day Index (SDI) is determined from a stress day factor (SD) and a crop susceptibility factor(C_s). This stress day factor is a measure of plant water deficit. Suggested equations are :

$$SD_i = (1.0 - ET/ET_p)$$

$$C_s = a\ (1.0 - ET/ET_p)$$

$$SDI = \sum_{i=1}^{n} (SD_i \times C_{si})$$

$$Y/Y_{max} = 1.0 - (A/Y_{max}) \sum_{i=1}^{n}[Cs_i(1.0 - ET/ET_p)_i]$$

where,

A = unit yield reduction per unit area per unit of Stress Day Index(SDI)

a = factor, depends on the physiological characteristics of the crops

Y = actual yield

Y_{max} = maximum yield

ET = evapotranspiration

ET_p = potential evapotranspiration

Another model was presented by Minhas et al (1974), who first developed an evapotranspiration prediction model for wheat as a function of available soil moisture only. The yield function he used was of the form ;

$$y = a\ [1-(1-x_1)^2]^{b_1}[1-(1-x_2)^2]^{b_2}......[1-(1-x_n)^2]^{b_n}$$

where,

y = yield

x_j = relative evapotranspiration in period j

a_1 and b_j = parameters fitted from data

Stewart, et al (1976) developed two models which utilized estimates of anticipated evapotranspiration deficits and growth stage sensitivities to predict actual evapotranspiration and yield for the season. The functions used were ;

$$Y = Y_{max} - Y_{max} \sum_{i=1}^{n} YRR_i \ (ET_{M(i)} - ET_{A(i)})/ET_M$$

where, ET_M = total evapotranspiration requirement

$ET_{M(i)}$ = evapotranspiration requirement for i^{th} growth period

$ET_{A(i)}$ = actual evapotranspiration in i^{th} growth period

YRR_i = yield reduction ratio in the i^{th} growth period

$$Y = Y_{max} - Y_{max} \ [\ B_o\ (ET_M - ET_A)/ET_M + (B - B_o)\ (ET_M - ET_A)/ET_M]$$

where, B_o = yield reduction ratio where evapotranspiration deficit sequencing is optimal

B = yield reduction ratio predicted for the season

The model uses the first function is reffered to as the Growth Stage Model and the other is reffered to as ET Deficit Sequence Model.

Hanks (1983) developed a simple model for both dry matter yield and grain yield. The equation to relate dry matter yield (Y), to transpiration is taken from that of de Wit (1971)

$$Y = mTR/E_o$$

where,

TR = transpiration

E_o = average fresh water evaporation rate

m = a crop factor

Karim (1985) determined the drought effects on yield of rice grown in Bangladesh using the function as ;

$$Y_{di} = Y_n \left(1 - \sum_{i=1}^{n} SI_i\right)$$

$$SI_i = SDI_i \times Cs_i$$

$$SDI_i = SD_i / GP_i$$

$$SD_i = GP - [R + CAP + d + WD_{sat}.d - \{Pl + WD_{sat}.d\ (1 - P)\}] / (ET_p \times K_c)$$

where,

GP = days in growth stage

R = rainfall at a specified probability

CAP = capillary contribution to the rootzone

d = standing water depth

WD_{sat} = water content at saturation

D = rootzone depth

Pl = percolation loss

P = fraction of W_a that can be allowed to be depleted without loss of yield

ET_p = potential evapotranspiration

K_c = crop coefficient

SDI = Stress Day Index

SI = stress index

Y_d = drought yield

Y_n = normal yield

The stress day index is determined from a stress day factor and a crop susceptibility factor. The stress day factor (SD) is a measure of the duration of plant water deficit. The crop susceptibility factor (C_s) depends on the species and stage of development of the given crop and indicates the plant susceptibility to a given water deficit. Crop susceptibility factor was calculated from various research data collected from BARC (1981, 1982, 1983), Karim et al (1981) and BRRI (1982, 1983) and Ahmed (1982) after Hiller and Clark (1971).

Karim (1985) determined the stress days in a growth stage from the total water available and potential use rate. Hence the distribution of rainfall during the growth stage has not been considered in scanning the stress days. The model was developed on the basis of this yield function. Although the function is very simple and was used in the model, it also has its limitations. It can not provide a quantitative means for determining the stress imposed on a crop during its growing season and fails to distinguish between continuous and intermittent stress development.

<u>Simulation Model</u> - Various yield simulation models were developed to predict the yield of a crop. The models use functional relationship between yield and water use.

A simulation model was developed by Martin, Watts, Gilley and Borcher (1981) to quantify the effect of deficit irrigation upon crop yield. A daily water balance was used to predict evaporation and transpiration from which crop yields were estimated. The model was applied for corn, sorghum, wheat and soybeans. Two types of models were used. For corn the model was based upon the reduction of crop yields due to transpiration reduction. The second type for other crops was based upon the reduction of crop and yield due to moisture stress. The maximum error in relative yield was found to be about 10%.

Yaron et al (1973) developed a soil moisture simulation model based on evapotranspiration predictions. Using wheat data, the author fitted parameters to a Mitscherlich function to predict the most reasonable estimate of yield obtainable under optimal conditions and used as the basis for the analysis of optimal irrigation policy. The Mitscherlich equation is :

$$y = y_{max} \prod_{i=1}^{n} (1 - B_i \, e^{-k_i x_i})$$

where,

y = actual yield

y_{max} = maximum yield

i = index of growth stage (i = 1,.........,n)

x_i = dimensionless soil moisture index

B_i and k_i = parameters

Hill and Hanks (1978) developed and applied a simulation model to predict yield for soyabeans and corn. The model considers the yield to be a function of transpiration and uses the relation given as ;

$$Y = mTR/E_o$$

For both the crops the results represented excellent agreement between the model predicted yields and actual field values. The application of the model to identify management practices that will maximize yields through water management or avoidance of dry periods has been demonstrated.

Hill, Hanks and Retta (1980) used the linear relationship of grain yields to evapotranspiration and transpiration to develop a model for predicting yield of alfalfa, barley, winter and spring wheat subjecting to varying levels of soil water deficits.

Pusposutordjo (1982) developed a yield model to observe the impact of irrigation at different growth stages of soybeans and peanuts. The model was applied to evaluate and improve the water management practice in Indonesia.

Hanks (1983) developed a model using the same yield function as Hill and Hanks (1978).

Agulto (1984) developed a model by adding a subroutine to the water and soil management crop yield (CRPSM) model developed by Hill et al (1968),The model was applied to predict the yield of corn and peanut in Phillipines. The model can be used to simulate the effect of different irrigation frequencies and levels in the yield of peanut. It can also be applied to predict the deep percolation loss in a corn or peanut field. The model used the yield function as :

$$Y/Y_p = \prod_{i=1}^{n} (TR/TR_p)^{\lambda_i} \times DAF$$

where

Y/Y_p = rato of actual to potential yield

TR/TR_p = ratio of actual to potential transpiration

λ = an exponent to allow weighing growth stage

DAF = drainage adjustment factor

So far a great deal of research work has been conducted and models were developed to estimate the yield of a crop. Most of the above mentioned research work have concentrated on upland crops. Few of the researchers developed yield functions for lowland crops. The yield function suggested by Karim (1985) is simple and requires very few experimental data and thus has been selected as the basis for model development.

BASIC CONSIDERATIONS AND MODEL DEVELOPMENT

During the growth of a plant, as it progresses from seed placement through harvest, various factors have greater or lesser influences depending upon particular growth stage of the plant. But the most important factor that influnces crop yield from one location to another or from one year to the next, is moisture availability.

The effect of water stress on rice yield can be estimated using Stress Day Index Concept (Karim,1985) :

$$Y/Y_{max} = 1.0 - SDI$$

where,

Y = actual yield

Y_{max} = maximum yield

SDI = seasonal Stress Day Index

The seasonal Stress Day Index can be obtained by:

$$SDI = \sum_{i=1}^{n} SD_i \times CS_i$$

where,

SD_i = stress day factor for growth stage, i

CS_i = crop susceptibility factor for growth stage, i

n = number of growth stages from transplanting to harvesting

The stress day factor of a particular growth stage can be estimated as :

$$SD_i = SSD_i/GP_i$$

where,

SSD_i = accumulated stress days for the growth stage, i

GP_i = number of days in the growth stage, i

The number of stress days in a particular growth stage can be obtained by scanning the stress days using daily water balance. A stress day occurs when the water content in the field falls below a threshold value. For rice such threshold value is the water content at 80% saturation level (Doorenbos and Kassam, 1977).

Estimation of Evapotranspiration

There are number of methods available to determine evapotranspiration. The present study has the option to estimate evapotranspiration by either of the following methods :

Pan Evaporation Method - Many studies over sevral decades have suggested the use of pan evaporation data to estimate potential evapotranspiration using a simple relationship

$ET_p = C_{et} \times E_{pan}$

where,

ET_p = Potential evapotranspiration

C_{et} = Coefficient, depending on reference crop and type of pan involved.

E_{pan} = Pan evaporation

Extreme care is needed in interpreting pan evaporation data to obtain reliable estimates of potential evapotranspiration. The value of C_{et} is a function of the kind of pan involved, the pan environment in relation to nearby surfaces, obstructions etc.

<u>Hargreaves method</u> - Hargreaves (1982) developed a very simple method to estimate evapotranspiration. The equation is ;

$$ET_o = 0.0075\ T.R_s$$

where ET_o is the reference crop evapotranspiration which is the rate of evapotranspiration of well watered green grass in langleys per day; T is the mean daily temperature in degree of Farenheit; R_s is the incident global radiation in langleys per day. Where measured incident radiation data are not available they can be estimated from recorded actual sunshine hours using the equation ;

$$R_s = (0.25 + 0.5\ n/N)\ R_a$$

where,

R_s = solar radiation

n = actual sunshine hours

N = possible sunshine hours

R_a = extraterrestrial radiation

The values of the possible sunshine hours and extraterrestrial radiation for a particular location can be detrmined from the latitude of the area. If the recorded sunshine hour data are not available the equations suggested by Hargreaves and Samani (16) can be used. The equation is ;

$$R_s = C_T \, (T_{max} - T_{min})^{1/2} \, R_a$$

where,

C_T = an emperical constant

R_a = extraterrestrial radiation

T_{max} and T_{min} = daily maximum and minimum temperature

<u>Penman Method [modified by Doorenbos and Pruitt]</u> - The Penman combination equation is considered superior to all other methods of estimating evapotranspiration using climatic dáta because of its theoretical basis. The equation is ;

$$ET_o = C \, [\, W . R_n + (1-W) . F(u) . (e_a - e_d)]$$

where, ET_o is the reference crop evapotranspiration, which is the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water, mm/day; W is the temperature related factor which is equal to $\Delta / (\Delta + \gamma)$, where Δ is the rate of change of saturation vapour pressure with temperature and γ is the psychrometric constant; R_n is net radiation in equivalent evaporation (mm/day); F(u) is the wind related function equal to $0.27(1 + U_2/100)$, where U_2 is the total wind run in km/day at 2m height; $(e_a - e_d)$ is the difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in m bar; and C is an adjustment factor to compensate for the effect of day and night weather condition.

Doorenbos and Pruitt (1977) discussed the calculation procedures to obtain the vapour pressure deficit from various humidity measurements. In Bangladesh humidity data are reported as relative humidity and hence the estimating equations are :

$$T_{mean} = (T_{max} + T_{min})/2$$

$$RH_{mean} = (RH_{max} + RH_{min})/2$$

$$e_a = 1.3329 \, EXP[21.07 - 5366.0 / (T_{mean} + 273.1)]$$

$$e_d = e_a \times RH_{mean}/100$$

where, T_{max} and T_{min} are maximum and minimum air temperatures in degree Celcius; RH_{max} and RH_{min} are maximum and minimum relative humidities. Where wind data are not collected at 2m height; they can be estimated by using the equation ;

$$U_2 = U_z\ (2/z)^{0.2}$$

where z is the elevation in meter at which U_z is measured. Supplementary equations for the modified Penman method are :

$$\gamma = C_p\ (P/0,622\ \lambda)$$

$$C_p = 0,242$$

$$\lambda = 595 - 0,51\ T$$

$$P = 1013 - 0,105\ (ELE)$$

where T is the mean air temperature in degree Celcius and ELE is the elevation in meters.

$$\Delta = 33,8639[\ 0,05904\ (0,00738\ T + 0,8072)^7 - 3,42\times10^{-6}\ ]$$

where T is the mean daily temperature in degree Celcius.

$$R_n = 0,77\ R_s - R_b$$

where, R_s is solar radiation, langleys/day ,

$$R_b = R_{bo} [a (R_s/R_{so}) + b]$$

R_{so} is the clear day solar radiation, langleys/day. Values of R_{so} can be obtained by developing an envelope curve from the plotted measured maximum solar radiation data. Where measured solar radiation data are not available, values given by Jensen (25) may be used.

$$R_{bo} = (a_1 + b_1 SQR(e_d)) (11.71) (10)^{-8}(T)^4$$

T is the mean daily temperature, degree Kelvin and e_d was defined earlier.

Values of **a**, **b**, a_1 and b_1 for a tropical country like Bangladesh can be taken as ; $a = 1.0$, $b = 0, a_1 = 0.39$ and $b_1 = -0.05$.

The above equations were synthesized to develop a computer program using BASIC.

The methods discussed above give the potential evapotranspiration of a reference crop. The potential evapotranspiration of a specific crop can be obtained by adjusting the plant growth stage to the potential evapotranspiration of the reference crop as expressed by;

$$ET_{crop} = K_c \times ETR$$

where ET_{crop} is the evapotranspiration of a disease-free crop grown in large fields under optimal soil water and fertility conditions; K_c is the crop coefficient; and ETR is the reference crop evapotranspiration.

Percolation

For paddy rice, the cultural practice is to maintain standing water in the field or at least saturated soil conditions and hence percolation loss is unavoidable and may be a major component of total water requirements. However it can be minimized through extensive puddling of the soil during the land preparation and avoiding drying and cracking of the soil. It varies widely among sites of similar soil type. The major physical factors influencing the percolation rate are: soil texture, anticedent water content of soil, location of water table and topography. For simplicity, the percolation rate is assumed to be at constant value from higher level of water content upto saturation point and it decreases linearly from the constant rate to zero at field capacity (Saleh, 1985).

$$P = P_{sat} \qquad \text{for } WD \geq WD_{sat}$$

$$P = P_{sat} \times (WD - WD_{field}) / (WD_{sat} - WD_{field})$$
$$\text{for } WD_{field} \leq WD < WD_{sat}$$

$$P = 0 \qquad \text{for } WD < WD_{field}$$

where,

P = percolation loss

P_{sat} = percolation at saturated moisture condition

P_{field} = percolation at field capacity

WD = total water in the field, mm

WD_{sat} = saturated water depth, mm

WD_{field} = water depth at field capacity

Water Balance

The different components of the water balance for rainfed paddies has been shown in Fig. 2 and the simplest form of dynamic water balance equation is ;

$$WD_i = WD_{i-1} + R_i + I_i - ET_i - P_i$$

where,

WD_i, WD_{i-1} = Total water in the field on i^{th} and $(i-1)^{th}$ day mm, respectively

R_i = rainfall on i^{th} day, mm

I_i= irrigation on i^{th} day, mm

ET_i= evapotranspiration on i^{th} day, mm

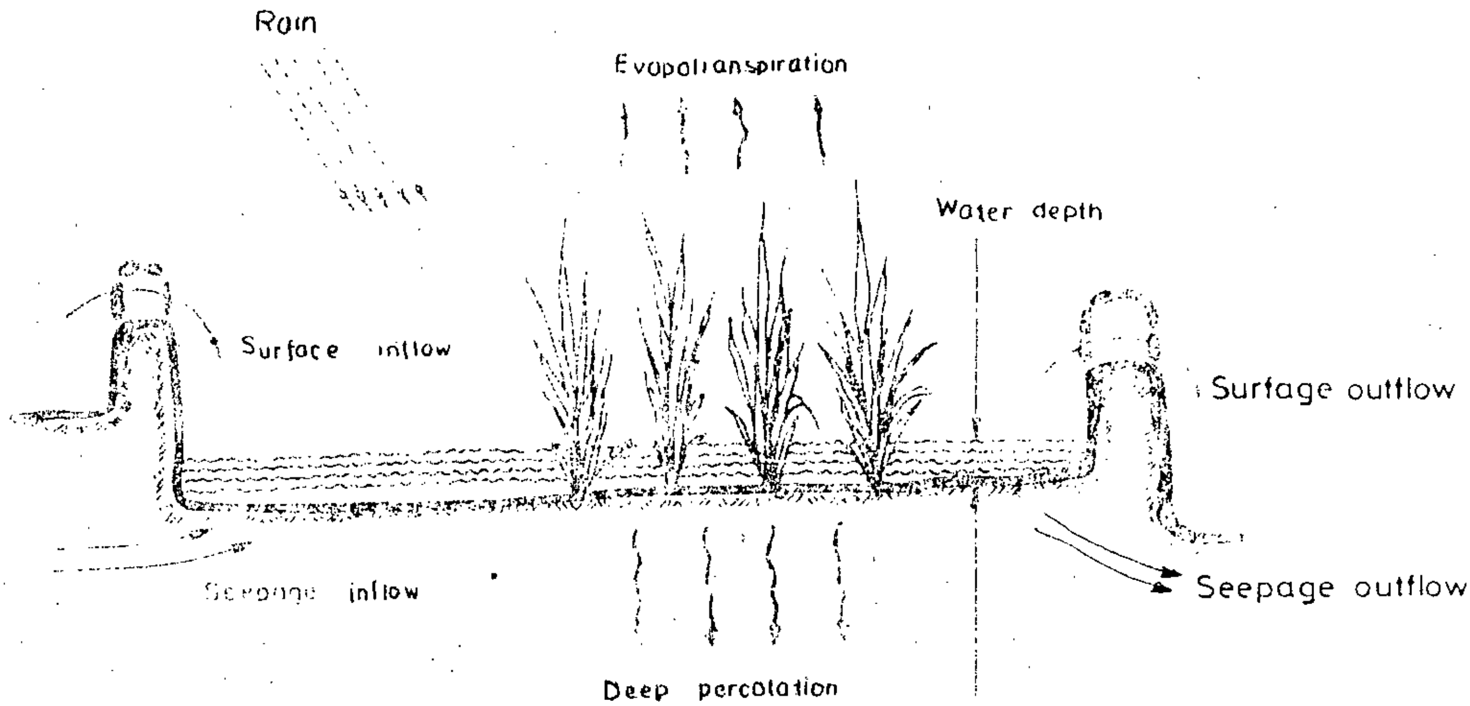


FIG. 2.--WATER BALANCE IN RAINFED PADDIES (MANALO)

P_i= percolation on i^{th} day, mm

Evapotranspiration is calculated from weather data and percolation is estimated on the basis of total water content of the previous day. Water in excess of a certain maximum depth is assumed lost as surface drainage, and WD_i is set equal to WD_{max}. Where, WD_{max} is the maximum allowable total water content in the paddy field. This is equal to the dike height plus the soil water content at saturation. Total water content at any level is equal to the summation of standing water in the paddy field and moisture content in the root zone.

Model Development and Description

The procedures outlined in the previous sections were synthesized and translated into a computer program using BASIC language. The model was developed on the basis of the following assumptions ;

a) Factors other than water stress do not have any effect on relative yield

b) Field drainage condition is such that the water in excess of dike height is drained without causing any damage to the crop.

c) Root depth remains constant throughout the growing season.

d) Drought in any growth stage does not affect the duration of other growth stages.

Fig.3 shows the conceptual framework of the model.

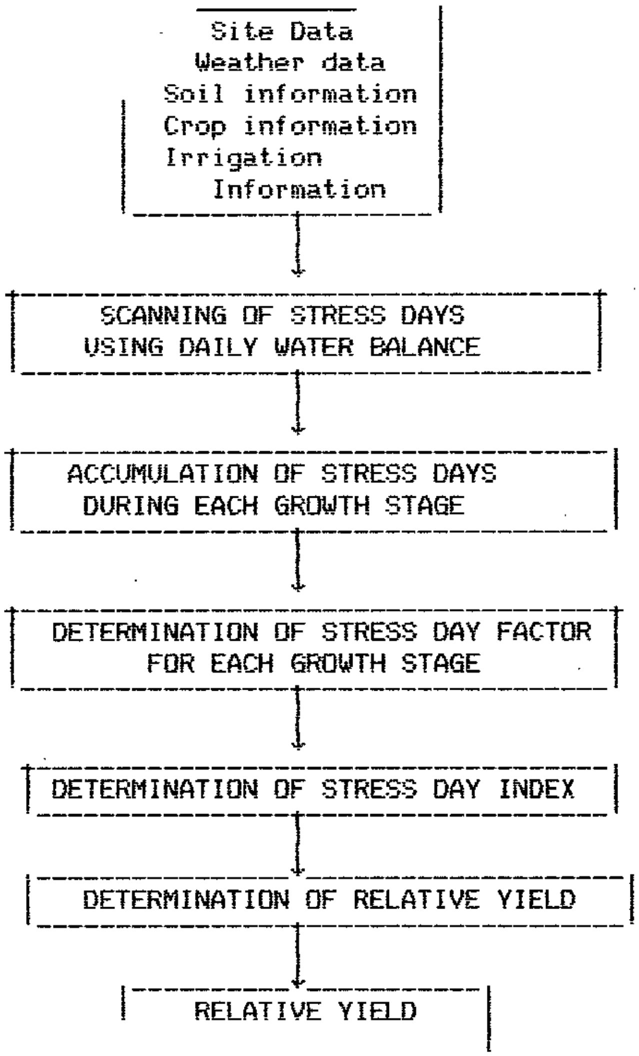


Fig.3 Conceptual framework of the model

The program was developed in BASIC, compatible with AMSTRAD PCW8256 personal microcomputer. It can easily be used in other microcomputers with a little modification depending on the system. The program developed was an interactive one. It requests for input data when it needs during the execution of computation. The program consists of six subroutines namely, EVAPO.SUB to calculate daily evapotranspiration by Pan Evaporation Method, EVPTHR.SUB to calculate evapotranspiration by Hargreaves Method, EVPTPN.SUB to calculate evapotranspiration by Penman Method, PER.SUB for percolation, JULIAN.SUB and DATE.SUB to convert dates to julian day and vice versa. The program provides option to select either Pan Evaporation Method, Hargreaves Method or Penman Method to calculate evapotranspiration. The program merges either with EVAPO.SUB or EVPTHR.SUB or EVPTPN.SUB as per option set by the user. The opted subroutine asks for the file name, starting and ending dates of data entry and directly reads the required weather data from the data file. It calculates and stores the daily evapotranspiration values. The program also provides the facility to enter evapotranspiration directly.

At the beginning the program asks for the required input data serially as :

1. Site data

i) Latitude (XLAT)

ii) Elevation (ELE)

iii) Cloudless day solar radiation (Rso) regression constants (CRso(i))

2. Crop information

i) Crop name

ii) Planting & Harvesting dates (PMONTH, PDATE; HMONTH,HDATE)

iii) Number of growth stages (NGP), their durations (N(X)) and respective crop susceptibility factor (Cs(X))

iv) Standing water depth (SWD) at the time of transplanting

v) Root zone depth (DR)

vi) Regression constants (CKr(i)) for crop coefficient curve

vii) Minimum moisture content (WDMIN) for crop stress development

3. Soil information

i) Saturated moisture content (WDSAT)

ii) Field capacity (WDFLD)

iii) Percolation rate under saturated condition (PSAT)

4. Water management information

i) Month (IRMONTH(Z)), day (IRDATE(Z))and amount (AMOUNT(Z)) of supplementary irrigation, if any

ii) Dike height (WDMAX)

In the next step the subroutine reads rainfall data from the data files. The program then starts performing daily water balance. It scans and accumulates the stress days for successive growth stages by comparing the calculated water depth with a threshold value (WDMIN). The threshold value is the water content below which stress occurs. If the calculated water depth in any day exceeds the maximum possible depth that can be stored in the field (WDMAX) the model assumes the water depth equal to WDMAX that day. For each growth stage the program computes the stress day factor from the accumulated stress days and duration of the growth stage. This process continues for the entire growing season (transplanting to harvesting) and Stress Day Index is calculated. The program finally calculates the relative yield which is given as output.

MODEL APPLICATION

Study Site

The yield reduction of rice due to drought and effect of supplemental irrigation can be well demonstrated by the model when applied to a drought prone area. Drought severly affects the northwest region of Bangladesh. Rajshahi lying in this region has been selected for model application.

The area is located at 24.37°N latitude and of 33.56°E longitude (Fig. 4). The climate of the area is characterized by two distinct season; the wet season from June to September and the dry season during the rest of the year. Mean monthly temperature for wet season is about 30°C and for dry season about 20°C while the relative humidity is 75 % for wet season and about 40 % for dry season. The average annual rainfall is about 1440 mm and most of it occurs during June to September. The distribution and monthly dispersion of rainfall of the area are shown in Fig. 5 and Fig. 6.

As indicated in Fig. 6, the rainfall in Rajshahi sharply decreases in the months of November and December. Rainfall in October is such that it can not reduce the effect of drought. Therefore drought of varying intensities during this period is evident. The dependable rainfall (75%

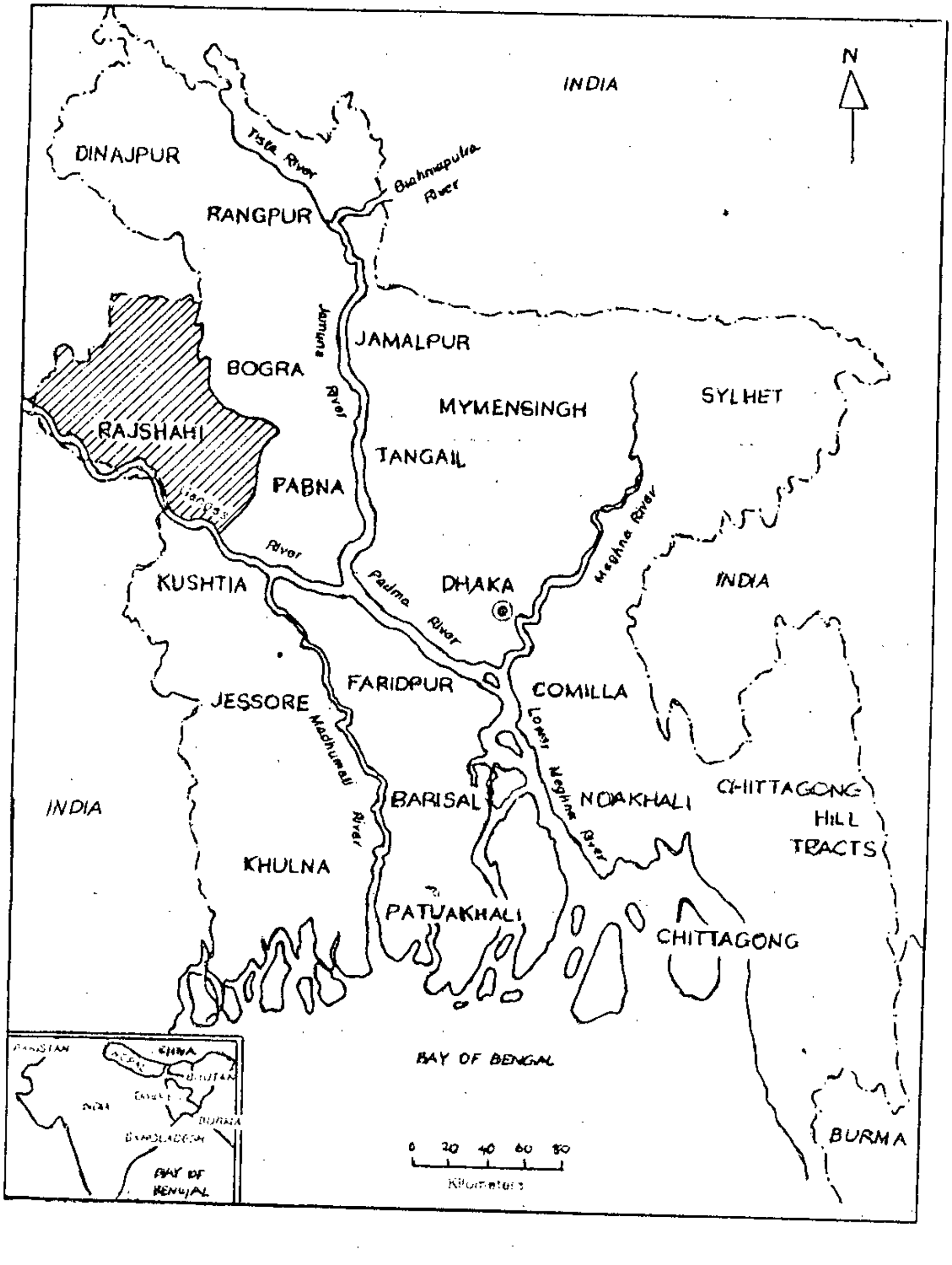


FIG. 4.-- MAP OF BANGLADESH SHOWING THE STUDY AREA

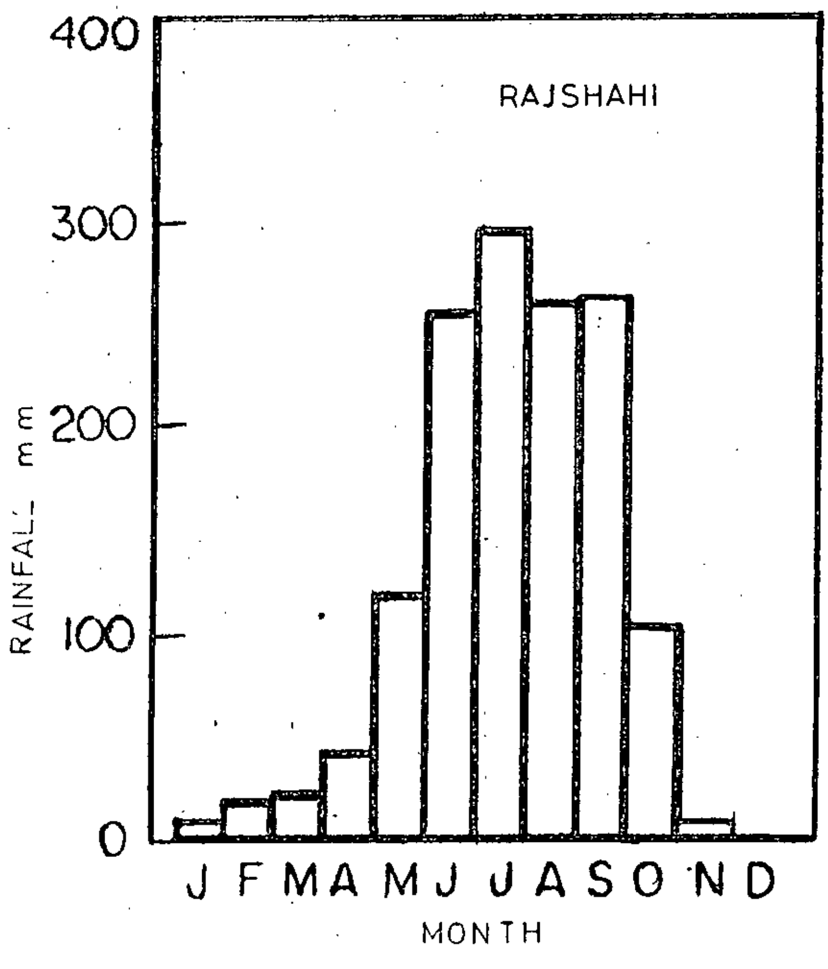


FIG. 5.--BAR DIAGRAM SHOWING THE AVERAGE MONTHLY RAINFALL IN THE STUDY AREA (MANALO)

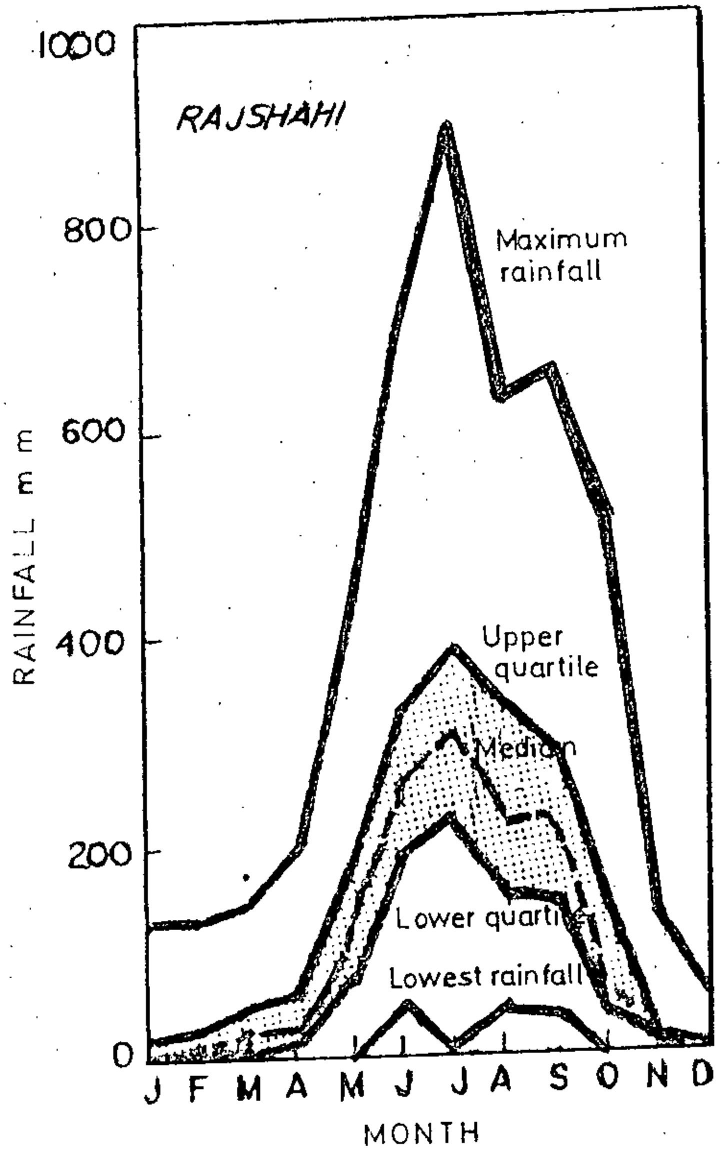


FIG. 6.--RAINFALL DISPERSION IN RAJSHAHI DISTRICT (MANALO)

probability level) for the month of November and December is very low as shown in Fig. 6.

Fig. 7 and Fig. 8 shows the physiographic units and soil associations of Rajshahi district. It is evident from the Fig. 7 and Fig. 8 that most of the land of Rajshahi falls under the physiographic units of the Ganges Floodplain and the Barind Tract. The soil association of these units are mostly of silt, silty clay and clay.

About 28% of the arable land in the study area is under Transplanted Aman cultivation (BBS, 1985). Transplanted Aman is cultivated generally from July/August to November/December. Therefore the final growing stages of Transplanted Aman is severly affected due to drought. The yield of Aman in the study site is 1.25 tons/hactares (BBS, 1985) although the area has the potential to yield 5.2 tons/hactares (Karim, 1985) due to favourable temperature and sunshine.

Input Data

Weather Data - The daily weather data recorded at Rajshahi for the years 1970-1980 were collected from Bangladesh Meteorological Department. These data include daily maximum and minimum temperatures, maximum and minimum relative humidity, actual sunshine hours, wind speed and rainfall. The data were analyzed to obtain the daily averages of

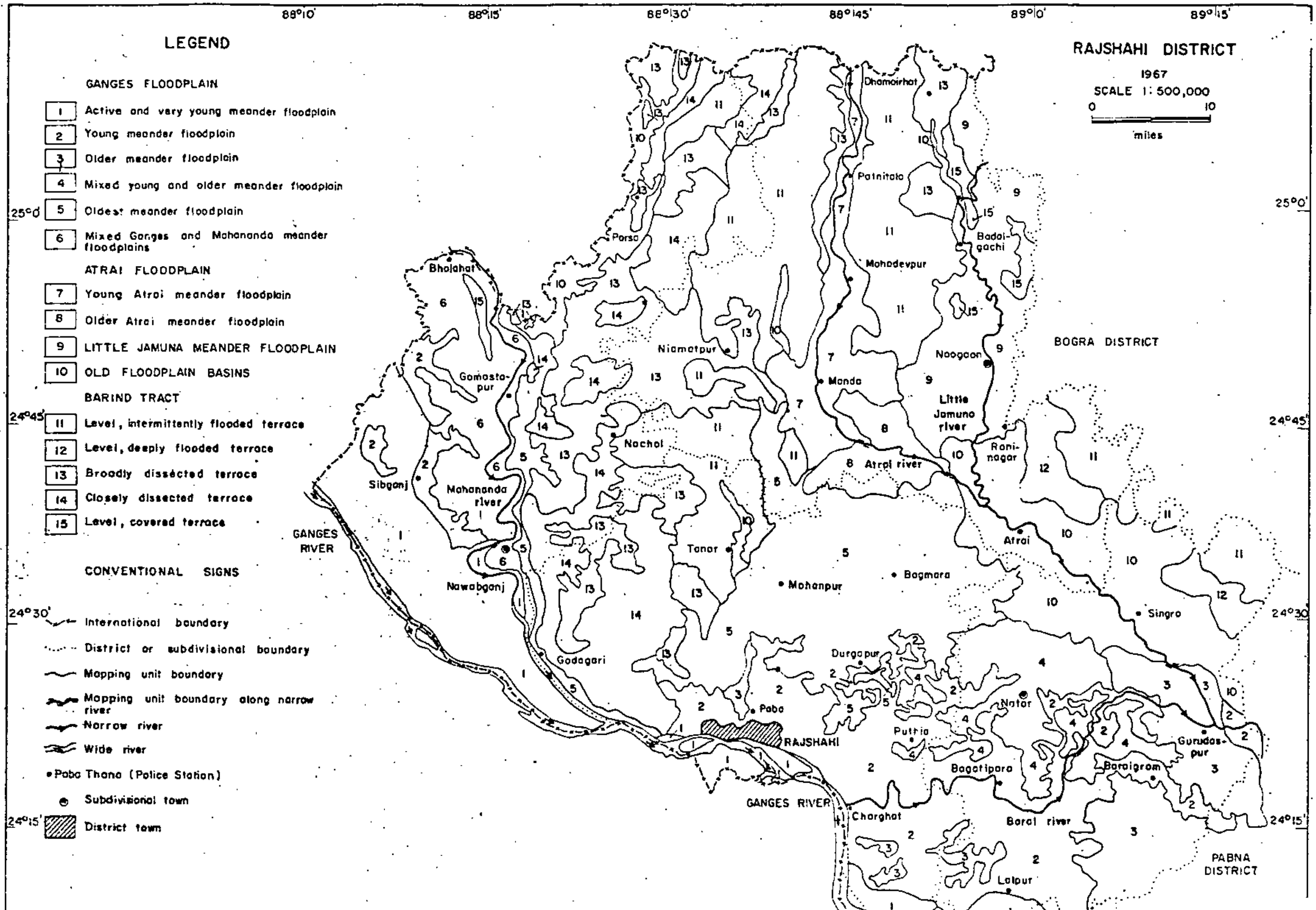
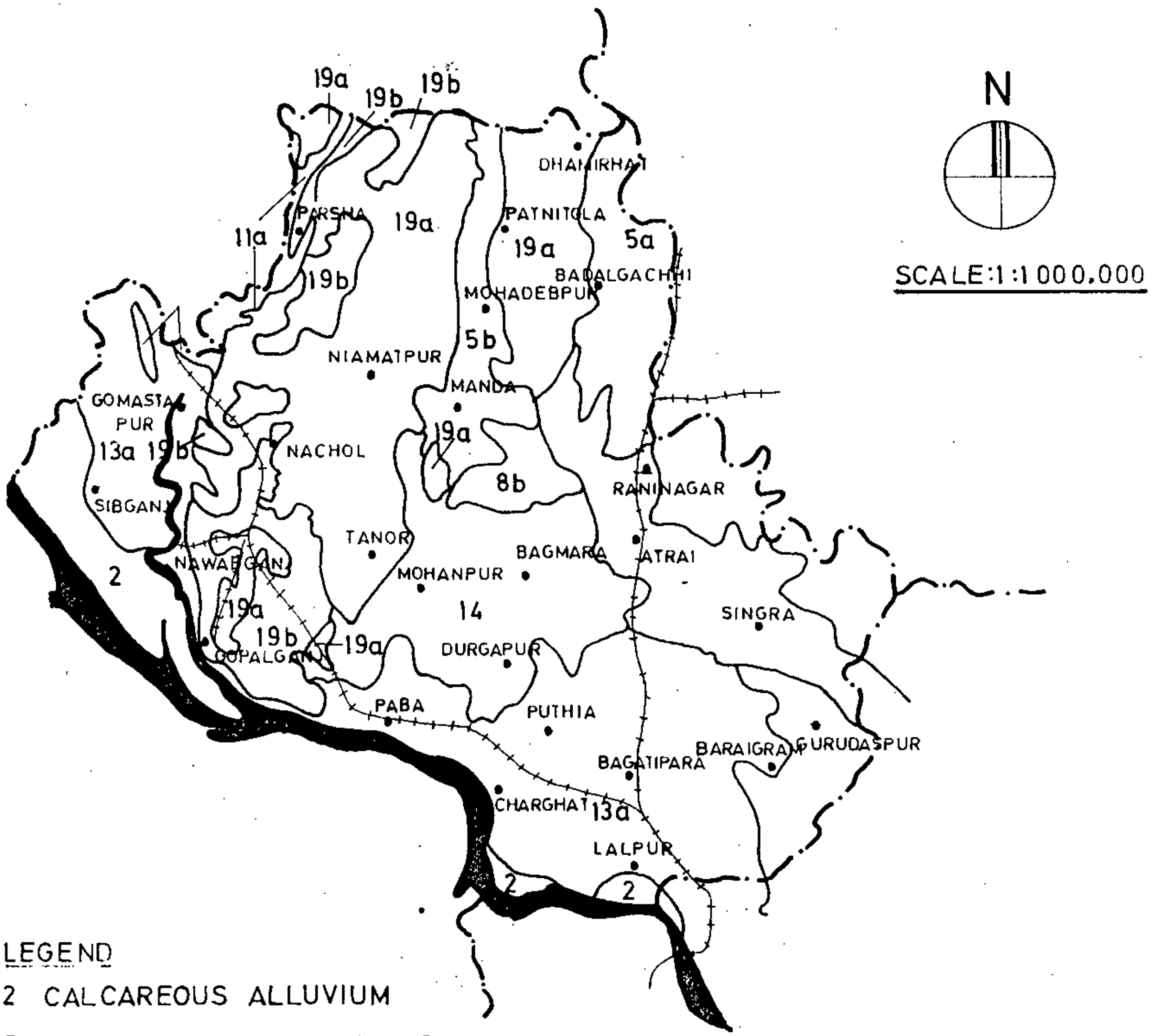


FIGURE 7 - PHYSIOGRAPHIC UNITS



LEGEND

2 CALCAREOUS ALLUVIUM

5 GREY FLOODPLAIN SOILS

8 GREY FLOODPLAIN SOILS AND NON CALCAREOUS DARK GREY FLOODPLAIN SOILS

11 ACID BASIN CLAYS

13 CALCAREOUS DARK GREY FLOODPLAIN SOILS AND CALCAREOUS BROWN FLOODPLAIN SOILS

14 CALCAREOUS DARK GREY FLOODPLAIN SOILS WITH LIME KANKAR

19 GREY TERRACE SOILS

FIGURE 8 SOIL ASSOCIANS OF RAJSHAHI DISTRICT these parameters to represent the normal weather condition of the study area. The daily average weather data were inserted into a data file and fed into the computer as input.

Crop Information - The crop information needed for the model application are planting and harvesting dates, crop coefficient, number of growth stages and their duration, respective crop susceptibility factors, the root zone depth, minimum moisture content for crop stress development, standing water depth at the time of transplanting, etc. The model assumed different planting dates for Transplanted Aman varying from July 1 to August 15 at an interval of five days. The stages of development and their susceptibility factors as reported by Karim (1985) were used. The growth stages and their crop susceptibility factors are given in the Table 3.

In this study, crop coefficient curve developed by Kaewkulaya (1980) was used. The crop coefficient curve used is shown in Fig. 9 and multiple regression constants are shown in Table 4.

The root depth for Transplanted Aman was taken as 30 cm. It was also assumed that stress would occur if total soil moisture within the root zone depth falls below 80% of the saturation value (Doorenbos and Kassam, 1979).

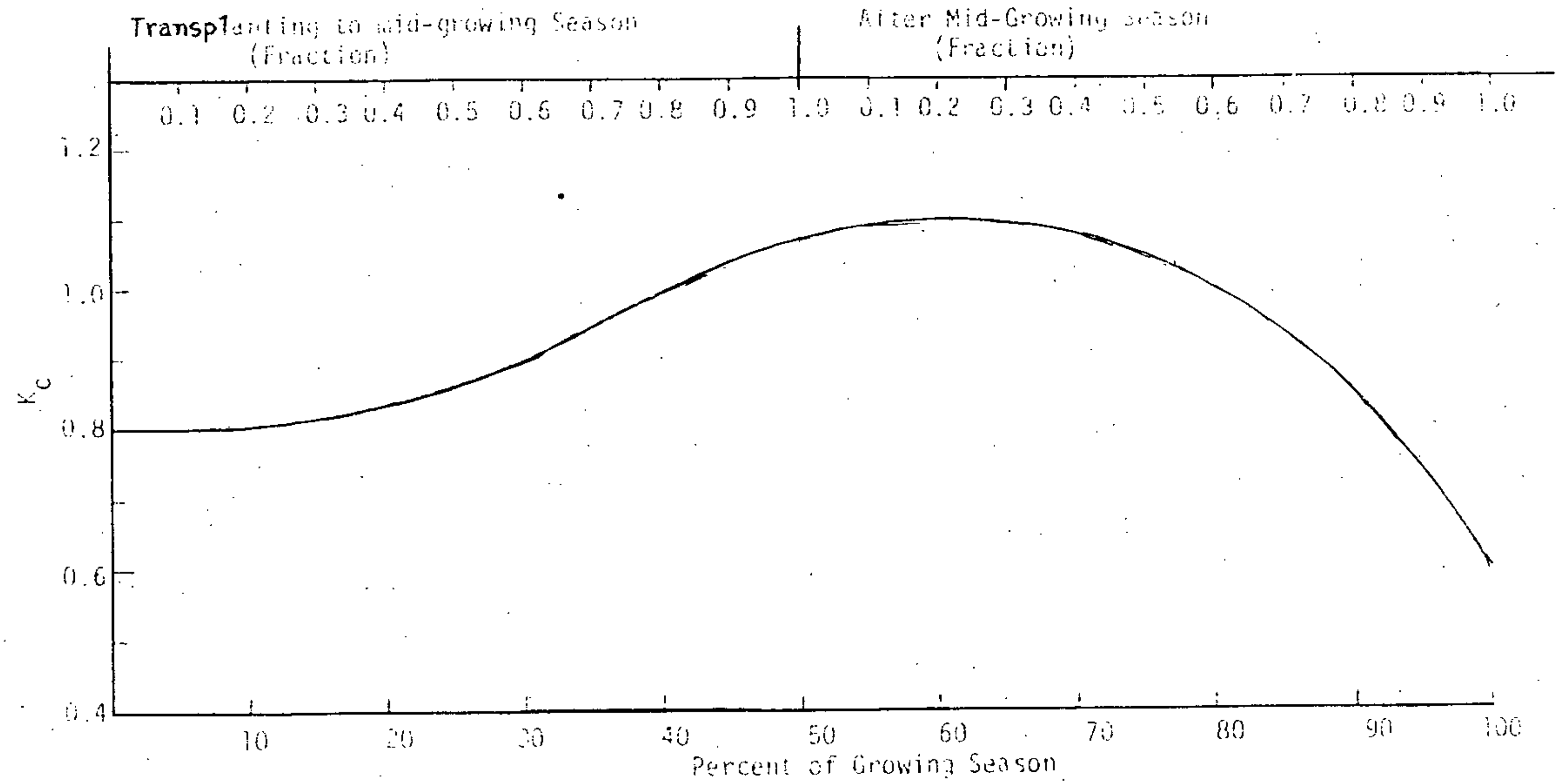


FIG. 9 --GROP COEFFICIENT CURVE FOR PADDY RICE AFTER TRANSPLANTING (KAEWKULAYA)

Table 3. Duration of Growth Stages and Respective Crop Susceptibility Factor for HYV Rice (Karim, 1985)

Growth stages (1)	Duration (2)	Crop Susceptibility Factor (3)
Transpalnting - Maximum tillering	45	0.28
Maximum tillering - Panicle initiation	5	0.40
Panicle initiation - Heading	30	0.48
Heading - Milk	10	0.59
Milk - Maturity	20	0.44

Table 4 Regression Constants of Crop Coefficient (K_c) Curve for Rice (Kaewkulaya, 1980)

Regression Constant (1)	Transplanting to Mid Growing Season (2)	After Mid Growing Season (3)
C_0	0.800	1.07
C_1	0.104	0.291
C_2	-0.650	-0.798
C_3	1.890	0.480
C_4	-1.080	-0.440

Soil Information - Moisture content at saturation and field capacity of soil varies significantly with soil texture. In this study, the moisture content of soil at field capacity and saturation were assumed to be 40% and 50% by volume respectively. As mentioned earlier the percolation rate under saturated condition (PSAT) varies widely among the sites having similar soil conditions. Hence, percolation rates of 3, 6 and 9 mm/day were assumed for moderate to heavy, light tomoderate and very light textured soils, respectively.

Management Practice - Three different dike heights, 75, 150 and 225 mm were considered in the model application. Supplemental irrigation was applied without considering any physical constraints and the amount was assumed to be 50 mm of a single application.

Application

Determination of Optimum Planting Date- The model was applied to calculate the relative yield of Transplanted Aman grown under rainfed condition for several planting dates starting from July 1, with an increment of five days upto August 15. Three types of land having percolation rate of 3, 6 and 9 mm and three dike heights 75, 150 and 225 mm were considered in the model application. The range of optimum planting date for each combination of land type and dike height was selected on the basis of model predicted relative yield.

Planning of Supplemental Irrigation- It was observed from the daily water balance that moisture stress did not occur before panicle initiation (third growth stage) indicating that supplemental irrigation might be required after panicle initiation. Thus the program was run several times by shifting the date of application of a single supplemental irrigation (50 mm) with an increment of two days, after panicle initiation till the relative yield was maximized. The date was considered as the best date for the first irrigation. When the desired level of yield was not achieved by the first irrigation, the best date for applying a second irrigation was similarly selected. This process was continued till the drought effect was completely avoided (100% relative yield).

RESULTS AND DISCUSSION

Model Verification

The model has been developed on the basis of a simple emperical yield function. It needs experimentally determined yield reduction factors as input. The model could not be verified due to lack of appropiate field data on effects of drought on rice yield. Since the crop susceptibility factors used in model application were derived from field experimental results, the model is expected to give reasonable estimates. Personal contact with Dr. Z. Karim revealed that the model predicted results represent actual field situations.

Application

Optimum Planting Date : The model predicted relative yield of rainfed Transplanted Aman rice for different dike heights (75 mm, 150 mm and 250 mm), percolation rates (3 mm/day, 6 mm/day and 9 mm/day) and planting dates are shown in Tables 5 to 7.

Table 5. reveals that yield loss of Transplanted Aman grown in moderate to heavy textured soil due to drought can be avoided by transplanting the seedling on or before July 11. The transplanting can be delayed by 15 days without any risk of yield loss if the dike height is increased to 225 mm. Since the percolation rate is low, more water

will be available to the plant if management practice allows the available water to be confined within the field by providing higher dikes. Yield is expected to be substantially reduced if planted later than August 10 irrespective of the dike height.

When grown in moderate to light textured soils with percolation rate of 6 mm/day, significant yield loss occured for planting dates later than July 11 (Table 6.). A yield loss of about 20% occured when planted as late as July 6. As indicated in Table 6., the yield loss is slightly decreased (2-4%) as the dike height is increased from 75 mm to 150 mm. But further raising of dike height did not have any effect on yield. This is because a greater portion of the rain water can be stored for use during drought as the dike height is increased upto 150 mm. Raising the dike height beyond 150 mm could not help avoiding drought effect due to non availability of excess rain water.

As shown in Table 7., for very light soils the yield dropped below the economic threshold level (relative yield of about 70%) as the planting was delayed beyond July 6. Even if planted on July 1 the yield was found to reduce by 26%. But the variation of dike height did not affect the relative yield for this percolation rate. This is probably due to non availability of enough water to store for use during drought. Planting on July 11 resulted in yield loss of as high as 43%.

TABLE 5, Relative Yield of Transplanted Aman Grown Under Rainfed Condition in Moderate to Heavy Textured Soil (percolation rate 3mm/day) on the Basis of Average Daily Rainfall for the Period 1970-1980 for Different Dike Heights and Planting Dates.

Planting Date	Relative Yield Y(%) For Dike Height		
	75 mm	150 mm	225 mm
(1)	(2)	(3)	(4)
July 11	100	100	100
July 16	91.2	100	100
July 21	78	100	100
July 26	64.8	95.6	100
July 31	50	80.2	86.8
Aug 5	14.7	67	80.2
Aug 10	negligible	50.1	60.4
Aug 15	negligible	20.6	32.4

TABLE 6. Relative Yield of Transplanted Aman Grown Under Rainfed Condition in Light to Moderate Textured Soil (percolation rate 6mm/day)on the Basis of Average Daily Rainfall for the Period 1970-1980 for Different Dike Heights and Planting Dates.

Planting Date	Relative Yield Y(%) For Dike Height		
(1)	75 mm (2)	150 mm (3)	225 mm (4)
July 1	87.5	87.5	87.5
July 6	80.8	82.4	82.4
July 11	67.6	71.4	71.4
July 16	56.6	58.2	58.2
July 21	30.8	32.4	32.4

TABLE 7. Relative Yield of Transplanted Aman Grown Under Rainfed Condition in Very Light Textured Soil (percolation rate 9mm/day)on the Basis of Average Daily Rainfall for the Period 1970-1980 for Different Dike Heights and Planting Dates.

Planting Date	Relative Yield Y(%) For Dike Height		
(1)	75 mm (2)	150 mm (3)	225 mm (4)
July 1	73.5	73.5	73.5
July 6	68.8	68.8	68.8
July 11	56.2	56.2	56.2
July 16	26	26	26

Supplemental Irrigation : Transplanted Aman is normally cultivated under rainfed condition and is subjected to yield loss due to droughts. But yield loss can be avoided by ensuring supplemental irrigation. The model predicted relative yield with supplemental irrigation for different dike heights (75 mm, 150 mm, 225 mm), percolation rates (3 mm/day, 6 mm/day and 9 mm/day) and planting dates are shown in Table 8 to 10.

As indicated in Table 8., three supplemental irrigations were required to avoid yield loss of Aman rice if transplanted before August 10 for moderate to heavy textured soil and dike height of 75 mm. The number of irrigation could be cut down to only one by raising the dike height to 150 mm. This is because the higher the dike height, higher was the value of effective rainfall. As the transplanting was delayed upto August 10, the number of supplemental oirrigation to avoid drought increased to four for low dike heights (75 mm) and three for medium to high dike heights (150 mm and 225 mm).

For moderate to light textured soil, three supplemental irrigations were required to avoid drought effects for low dike height and transplanting date of as late as July 16 (Table 9). The number of irrigations increased to four if the transplanting was done later. Raising of dike height reduced the number of irrigation. But it was not as effective as for moderate to heavy textured soil.

TABLE 8.--Optimal Dates of Supplemental Irrigations and Their Impact on Relative Yield of HYV T. Aman Rice Grown in Moderate to Heavy Soils (percolation rate 3 mm/day) on the Basis of the Average Daily Rainfall for the Period 1970-1980

Planting Date (1)	Dike Height mm (2)	No. of Irrigation Applied (3)	Best Date of Irrigation (4)	Relative Yield (%) (5)
July 31	75	Nil	-	50
		1st	Oct 2	75.8
		2nd	Nov 6	95.6
		3rd	Nov 14	100
	150	Nil	-	80.2
		1st	Oct 15	100
	225	Nil	-	86.8
		1st	Sept 27	100
Aug 5	75	Nil	-	14.7
		1st	Oct 27	64.8
		2nd	Nov 6	84.6
		3rd	Nov 14	100
	150	Nil	-	67
		1st	Oct 5	100
	225	Nil	-	80.2
		1st	Oct 7	100
Aug 10	75	Nil	-	Negligible
		1st	Oct 27	44.2
		2nd	Nov 6	71.4
		3rd	Nov 12	91.2
		4th	Nov 20	100
	150	Nil	-	50.1
		1st	Nov 2	71.4
		2nd	Nov 14	91.2
		3rd	Nov 22	100
	225	Nil	-	60.4
		1st	Nov 10	80.2
		2nd	Nov 18	100

TABLE 9.--Optimal Dates of Supplemental Irrigations and Their Impact on Relative Yield of HYV T. Aman Rice Grown in Moderate to Light Soils (percolation rate 6 mm/day) on the Basis of Average Daily Rainfall for the Period 1970-1980

Planting Date (1)	Dike Height mm (2)	No. of Irrigation Applied (3)	Best Date of Irrigation (4)	Relative Yield (%) (5)
July 11	75	Nil	-	67.6
		1st	Oct 13	94
		2nd	Oct 19	98.4*
		3rd	Oct 25	100
	150	Nil	-	71.4
		1st	Oct 11	95.6
		2nd	Oct 21	100
	225	Nil	-	71.4
		1st	Oct 11	95.6
		2nd	Oct 21	100
July 16	75	Nil	-	56.6
		1st	Oct 15	83
		2nd	Oct 21	98.4
		3rd	Oct 29	100
	150	Nil	-	58.2
		1st	Oct 15	84.6
		2nd	Oct 21	100
	225	Nil	-	58.2
		1st	Oct 15	84.6
		2nd	Oct 21	100

TABLE 9.-- Continued

Planting Date (1)	Dike Height mm (2)	No. of Irrigation Applied (3)	Best Date of Irrigation (4)	Relative Yield (%) (5)
July 21	75	Nil	-	30.8
		1st	Sept 21	38.3*
		2nd	Oct 15	71.4
		3rd	Oct 25	93.4
		4th	Nov 2	100
	150	Nil	-	32.4
		1st	Oct 13	69.2
		2nd	Oct 23	91.2
		3rd	Oct 31	100
	225	Nil	-	32.4
		1st	Oct 13	69.2
		2nd	Oct 23	91.2
		3rd	Oct 31	100

* Additional irrigation was required to obtain 100% yield

As indicated in Table 10, the number of supplemental irrigations increased as the transplanting was delayed more and more, Raising of dike height could not reduce the number of irrigation.

TABLE 10.--Optimal Dates of Supplemental Irrigations and Their Impact on Relative Yield of HYV T. Aman Rice Grown in Very Light Soils (percolation rate 9 mm/day) on the Basis of the Average Daily Rainfall for the Period 1970-1980

Planting Date (1)	Dike Height mm (2)	No. of Irrigation Applied (3)	Best Date of Irrigation (4)	Relative Yield (%) (5)
July 1	75-225	Nil	-	73.5
		1st	Sept 19	91.2
		2nd	Oct 13	100
July 11	75-225	Nil	-	56.2
		1st	Sept 13	62.64*
		2nd	Oct 7	71.4
		3rd	Oct 13	91.2
		4th	Oct 21	100
July 16	75-225	Nil	-	26
		1st	Sept 19	32.4*
		2nd	Oct 9	60.4
		3rd	Oct 15	80.2
		4th	Oct 25	100

* Additional irrigation was required to obtain 100% yield

CONCLUSIONS AND SUGGESTION FOR FURTHER STUDY

Conclusion

A computer model that can be used in predicting the impact of various water management options on rice yield has been developed. The usefulness of the developed model has been demonstrated through its application in a drought prone area (Rajshahi) to determine the optimum planting date and optimum irrigation schedule for Transplanted Aman grown under different soil conditions and farm management practices.

Based on results of model application the following conclusions can be made:

1. To avoid significant yield loss due to drought the transplanting of Aman rice in the study area should be done on or before July 21 for moderate to heavy textured soil, July 11 for light to moderate textured soil and July 6 for very light textured soil.

2. Land management (adjustment of dike height) can not help in reducing drought effect on Transplanted Aman yield grown in moderate to light textured soil but can be an effective way to reduce drought effect for moderate to heavy textured soil.

3. If transplanted later than the above dates supplemental irrigation is necessary during final growth stages (October/November) to avoid yield loss due to drought.

4. The icremental benifit of supplemental irrigation decreases as the number of application increases.

5. The number of supplemental irrigation to obtain a desired yield level largely depends on the soil type and date of transplanting.

6. The number of application of supplemental irrigation can be reduced by raising the dike height from low to medium (75mm to 150 mm) for medium and heavy textured soil. But the adjustment of dike height can not help cutting down the number of application for very light textured soil.

In the model application most of the data were obtained from literature and judicious assumptions. Hence further verification of the data and updating of the conclusion may be necessary. Nevertheless the model provides a useful tool to the decision makers dealing with irrigation planning for rice.

Suggestion for Further Study

The following recommendations are made for further refinement of the present work :

1. Systematic collection of field data to provide a basis for validation of the model.

2. Field experiments to determine percolation losses from the rice lands under intermittent irrigation.

3. Investigation to determine the mimimum soil moisture below which the yield of rice crop will be significantly reduced.

4. Field experiments to verify the values of the crop suscetibility factor used in this study.

5. An economic analysis of the cost of supplemental irrigation and the corresponding return from yield.

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Appendix I.-- Notations

NOTATIONS

A -- Unit yield reduction per unit area per unit of Stress Day Index

a(w) -- Yield reduction factor for stress applied on a growth stage

a -- Factor

a1 -- Parameter

B -- Parameter

b -- Parameter

B -- Yield reduction ratio where ET deficit sequencing is optimal

B_o -- Yield reduction ratio predicted for the season

CAP -- Capillary contribution

C -- Adjustment factor

C_T -- Imperical constant

C_{et} -- Pan coefficient

C_s -- Crop susceptibility factor

D -- Root zone depth

d -- Standing water depth

DAF -- Drainage adjustment factor

ET -- Evapotranspiration

ET_P -- Potential evapotranspiration

ET_M -- Total ET requirement

ET_A -- Actual ET

E_o -- Average fresh water evaporation

E_{pan} -- Pan evaporation

ET_o -- Reference crop ET

NOTATIONS (Continued)

e_a -- Saturation vapour presuure at mean air temperature

e_d -- Mean actual vapour pressure

F(u) -- Wind related function

Gr -- Relative growth

GP -- Growth period

I_e -- Function for potential growth for one irrigation cycle

K_c -- Crop coefficient

K -- Parameter

λ -- Relative sensitivity of the crop to water stress

m -- Crop factor

N -- Possible sunshine hours

n -- Actual sunshine hours

P -- Percolation

P_{sat} -- Percolation at saturated condition

P_{field} -- Percolation at field capacity

R -- Rainfall

R_s -- Incident global radiation

R_a -- Extraterrestrial radiation

RH_{max} -- Maximum relative humidity

RH_{min} -- Minimum relative humidity

RH_{mean} -- Average relative humidity

R_n -- Net radiation

SD -- Stress day factor

NOTATIONS (Continued)

SI -- Stress index

SDI -- Stress Day Index

SSD -- Accumulated stress days

T -- Length of irrigation season

t -- Length of irrigation cycle

TR -- Transpiration

TR_p -- Potential transpiration

T_{max} -- Maximum temperature

T_{min} -- Minimum temperature

T_{mean} -- Mean temperature

U_z -- Wind speed at elevation z

WD -- Soil moisture content

W -- Temperature related factor

WD_{sat} -- Saturated moisture content

WD_{field} -- Moisture content at field capacity

x -- Relative evapotranspiration

Y -- Actual yield

Y_{max} -- Maximum yield

Y_d -- Drought yield

YRR -- Yield reduction ratio

Y_n -- Normal yield

z -- Elevation

Appendix II.-- Definition of Terms

DEFINITION OF TERMS

Aman - Rice growing season from August-December

Aus - Rice growing season from March-August

Boro - Rice growing season from December-May

Crop Susceptibility Factor - Factor that indicates susceptibility of plant to a given water deficit.

Drought - Phenomenon that occurs due to non occurrence of rain

Dike - an earth wall surrounding the rice field to provide standing water in the field and for weed control

Economically Acceptable Yield - About 70% relative yield

Kharif I - Crop growing season during March-April

Kharif II - Crop growing season during September-October

Optimum Planting Date - Transplanting date for maximum relative yield

Percolation - Downward movement of water beyond the rootzone to the water table

Rabi - Winter crop growing season during Nvember-March

Rainfed Cultivation - When rice is only on rain for its soil moisture requirements

Stress Day - A day in which total eqivalent water depth in the field falls below 80% of saturation

Supplemental Irrigation - Irrigation that supplements rain

Upland Crop - Crop grown without standing water in the field

Crop Water Requirements - It here includes evapotranspiration and percolation

Appendix III.-- Listing of the Computer Model,
Sample Input and Output

```
5 REM DIMENSION DECLARATION
10 DIM MONTHX(12),N(6),Cs(6),IrMNTH(6),IrDATE(10),AMOUNT(10),IrJUL(10),SD(6),WD(
365),IRRIG(365),PRRAIN(365),PER(365),ETO(365),TMEAN(
365),ASSMN(365)
20 FOR K = 1 TO 12
30 READ MONTHX(K)
40 NEXT
50 DATA 31,28,31,30,31,30,31,31,30,31,30,31
60 READ YES$,NO$ :DATA "YES",""
62 READ CK11,CK12,CK13,CK14,CK15
64 DATA 0.80,0.104,-0.647,1.89,-1.08
66 READ CK21,CK22,CK23,CK24,CK25
68 DATA 1.07,0.291,-0.798,0.48,-0.44
70 INPUT "IS THE GROWING YEAR IS A LEAP YEAR ?",Y$
80 IF Y$=YES$ THEN MONTH(2) = MONTH(2) + 1
81 REM SITE DATA
85 INPUT "WHAT IS THE LATITUDE AND ELEVATION OF YOUR AREA ?",XLAT,ELEV
86 REM REGRESSION CONSTANTS FOR RSO
90 REM Crop Informations
92 INPUT "WHAT IS THE NAME OF THE CROP ?",CROP$
94 PRINT "WHAT IS THE PLANTING MONTH AND DATE FOR "CROP$"[ENTER MONTH AS THE SER
IAL NO 1 FOR JANUARY AND THEN ENTER DATE SEPARATED B
Y A COMMA]":INPUT PMONTH,PDATE
98 INPUT "WHAT IS THE NAME OF THE CROP ?",CROP$
105 MONTH = PMONTH : DATE = PDATE
107 CHAIN MERGE "JULIAN.SUB",108,ALL
108 GOSUB 35000 : PJUDA = JUDA
109 PRINT PJUDA
110 PRINT "WHAT IS THE HARVESTING MONTH AND DATE FOR "CROP$ :INPUT HMONTH,HDATE
140 MONTH = HMONTH : DATE = HDATE
150 GOSUB 35000 : HJUDA = JUDA
151 PRINT HJUDA
160 INPUT "HOW MANY GROWTH PERIODS ARE THERE ?",NGP
170 FOR X = 1 TO NGP-1
180 PRINT "HOW MANY DAYS BETWEEN GROWTH PERIOD-"X" AND GROWTH PERIOD-"X+1" ARE T
HERE AND WHAT IS THE RESPECTIVE CROP SUCCEPTIBILITY
FACTOR ?":INPUT N(X),Cs(X)
190 NEXT
191 PRINT "WHAT IS THE STANDING WATER LEVEL AT THE TIME OF TRANSPLANTING":INPUT
SWD
192 INPUT "DEGREE OF REGRESSION CURVE",NDR
193 FOR i = 1 TO NDR
194 PRINT "coefficient of";i;"order : input CRso(i) :next
195 INPUT "WHAT IS THE MINIMUM HEIGHT OF WATER FOR STRESS DEVELOPMENT ?",WDMIN
205 REM SOIL INFORMATION
210 INPUT " WHAT IS THE SATURATED MOISTURE CONTENT IN HEIGHT OF WATER IN MM ?",W
DSAT
220 INPUT " WHAT IS THE FIELD CAPACITY OF THE SOIL ?",WDFLD
230 INPUT " WHAT IS THE PERCOLATION UNDER SATURATED CONDITION ?",PSAT
240 INPUT " HAVE YOU APPLIED ANY SUPPLIMENTARY IRRIGATION ?",Y$
250 IF Y$ = NO$ THEN GOTO 320
260 INPUT " HOW MANY IRRIGATION/S HAVE YOU APPLIED ?",Irri
270 FOR Z = 1 TO Irri
280 PRINT "MONTH,DATE AND AMOUNT FOR IRRIGATION-"Z"(ENTER THE SERIAL NO OF MONTH
 THEN DATE THEN AMOUNT IN MM OF HEIOGHT OF WATER)" :
INPUT IrMNTH(Z),IrDATE(Z),AMOUNT(Z)
290 MONTH = IrMNTH(Z) : DATE = IrDATE(Z)
295 INPUT " WHAT IS THE DIKE HEIGHT IN MM ?",WDMAX
300 GOSUB 35000 : IrJUL(Z) = JUDA
310 NEXT
320 INPUT " DO YOU HAVE EVAPORATION DATA ?",Y$
```

```
330 IF Y$ = NO$ THEN GOTO 340
335 CHAIN MERGE "RDEVPO.SUB",337,ALL
337 GOSUB 55000
339 INPUT "INSERT THE PROGRAM DISK",Y$ : GOTO 400
340 INPUT " DO YOU WANT TO ENTER EVAPOTRANSPIRATION DIRECTLY ?",Y$
350 IF Y$ = NO$ THEN GOTO 360
352 CHAIN MERGE "RDEVPT.SUB",354,ALL
354 GOSUB 37000
355 INPUT " INSERT THE PROGRAM DISK ",Y$ :GOTO 402
360 INPUT " DO YOU WANT TO ESTIMATE EVAPOTRANSPIRATION BY HARGRIEVES METHOD ?",Y
$
370 IF Y$ = NO$ THEN GOTO 390
375 CHAIN MERGE "EVPTHR.SUB",377,ALL
377 GOTO 27000 : GOTO 404
379 GOTO 404
390 INPUT " DO YOU WANT TO ESTIMATE EVAPOTRANSPIRATION DATA BY PENNMAN METHOD ?"
,Y$
395 IF Y$ = NO$ THEN GOTO 320
397 CHAIN MERGE "PENMAN.SUB",398,ALL
398 GOSUB 20500
399 INPUT "Insert your program disk", Y$ : GOTO 406
400 CHAIN MERGE "RDRAIN.SUB",401,ALL,DELETE 55000-55220
401  GOSUB 56500 : GOTO 410
402 CHAIN MERGE "RDRAIN.SUB",403,ALL,DELETE 37000-37140
403 GOSUB 56500 :GOTO 410
404 CHAIN MERGE "RDRAIN.SUB",405,ALL,DELETE 27000-27160
405 GOSUB 56500 :GOTO 410
406 CHAIN MERGE "RDRAIN.SUB",407,ALL,DELETE 20500-20850
407 GOSUB 56500
410 J = PJUDA: WD(J) = WDSAT + 50  :SDI = 0: Z=1 : L=2
420 FOR  I = 1 TO NGP-1
421 XSD = 0: lmx = N(I) : IF I = 1 THEN lmx = lmx -1
422 FOR  K = 1 TO lmx
423 IF J > 365 THEN J = 1
424 lm = J + 1 : IF J = 365 THEN lm = 1
426 GOSUB 11000
430 IF Z > Irri THEN IRRIG(lm) = 0 : GOTO 444
440 IF J = IrJUL(Z) THEN IRRIG(lm) = AMOUNT(Z) : Z = Z+1
443 H = HJUDA : IF PJUDA > H THEN H = H + 365
444 R =L/110
445 IF R > 0.5 THEN GOTO 448
446 Kr = CK11 +(CK12+(CK13+(CK14+CK15*R)*R)*R)*R
447 GOTO 450
448 Kr = CK21 +(CK22+(CK23+(CK24+CK25*R)*R)*R)*R
450 WD(lm) = WD(J) +  PRRAIN(lm) + IRRIG(lm) - PER(lm)-Kr*ETO(lm): IF WD(lm) > W
DMAX + WDSAT THEN WD(lm) = WDMAX + WDSAT
452 IF WD(lm) < 0 THEN WD(lm) = 0
455 PRINT "JDAY="lm;"WD="WD(lm);"RAIN="PRRAIN(lm);"PER="PER(lm);"ETO="ETO(lm);"K
r="Kr;"IRIG="IRRIG(lm)
460 IF WD(lm) >= WDMIN THEN GOTO 480
470 XSD = XSD + 1: PRINT "XSD = "XSD
480 J = J + 1 :L=L+1
485 NEXT
500 SD(I) = XSD/N(I) :PRINT "I = "I;" N(I) ="N(I);"SD(I) = ";SD(I);"Cs(I) ="Cs(I
)
510 SDI = SDI + SD(I)*Cs(I):PRINT "SDI = "SDI
520 NEXT
530 RYEILD = 100 * (1-SDI): IF RYEILD < 0 THEN RYEILD = 0
540 PRINT "YEILD SIMULATION MODEL FOR RICE "
550 PRINT " THE MODEL IS RUNNING FOR THE CROP "CROP$
560 PRINT "PLANTING DATE ="PJUDA;"  "; "RELATIVE YEILD ="RYEILD;"%"
```

```
570 PJUDA = PJUDA + 3: HJUDA = PJUDA + 110 :IF PJUDA > 240 THEN GOTO 580
575 GOTO 375
580 END
585 REM PER.SUB
11000 IF WD(J-1) > WDMAX THEN WD(J-1) = WDMAX
11010 IF WD(J-1) >= WDSAT THEN PER(J) = PSAT
11020 IF WD(J-1) <= WDFLD THEN PER(J) = 0
11030 PER(J) = PSAT * WD(J-1)/(WSAT-WDFLD)
11040 RETURN
11045 REM MONTH.SUB
20000 IF MONTH = 1 THEN DAY = 31 : GOTO 20120
20010 IF MONTH = 2 THEN DAY = 28 : GOTO 20120
20020 IF MONTH = 3 THEN DAY = 31 : GOTO 20120
20030 IF MONTH = 4 THEN DAY = 30 : GOTO 20120
20040 IF MONTH = 5 THEN DAY = 31 : GOTO 20120
20050 IF MONTH = 6 THEN DAY = 30 : GOTO 20120
20060 IF MONTH = 7 THEN DAY = 31 : GOTO 20120
20070 IF MONTH = 8 THEN DAY = 31 : GOTO 20120
20080 IF MONTH = 9 THEN DAY = 30 : GOTO 20120
20090 IF MONTH = 10 THEN DAY = 31 : GOTO 20120
20100 IF MONTH = 11 THEN DAY = 30 : GOTO 20120
20110 IF MONTH = 12 THEN DAY = 31 : GOTO 20120
20115 REM JULIAN.SUB
20120 RETURN
20500 DIM TMEAN(200),RHMEAN(200), ASSMN(200), VELMN(200)
20510 CHAIN MERGE "RDTHAV.SUB",20512,ALL
20512 GOSUB 43000
20630 FOR J = PJUDA TO HJUDA
20640 C = 1: DEL = 2*(0.00738*TMEAN(J)+0.8072)^7-0.00116
20650 CP = 0.24 :PA= 1013 - 0.1055*ELEV : LAMDA = 595 - 0.51*TMEAN(J)
20660 E = 0.622 : a = 1.35 : b = -0.35 : a1 = 0.34 : b1 = -0.044
20670 GAMMA = CP*PA/(LAMDA*E)
20680 XT = 0.017453*XLAT :Y = COS(0.017214*(J+192))
20690 DR = 0.40876 *Y :SR = 1.00028 + 0.03269*Y
20700 Z = -TAN(XT)*TAN(DR) : AZ = ATN(SQR(1-Z^2)/Z)
20710 PSS = 7.63942*AZ : AR = AZ*SIN(XT)*SIN(DR)
20720 BR = COS(XT)*COS(DR)*SIN(AZ)/SR
20730 RA = 916.732*(AR+BR)
20740 RS = (0.25+0.5*ASSMN(J)/PSS)*RA
20750 RSO = 0.166*10^-4*J^3 +0.205*10^-1*J^2 +0.567*10*J + 0.381*10^3
20760 EAF = 1.3329*EXP(21.07-5336/(TMEAN(J)+273.1))
20770 ED = RHMEAN(J)*EAF/100
20780 RBO = (a1 + b1*SQR(ED))*11.71*10^-8*(TMEAN(J) + 273) ^4
20790 RB = RBO*(a +RS/RSO*b)
20800 W= DEL/(DEL + GAMMA)
20810 U2M = VELMN(J)*(2/ELEV)^0.2
20820 FV = 0.27*(1+0.01*U2M)
20830 RNET = (0.77*RS - RB) * 10/LAMDA
20840 ETO(J) = C*(W*RNET +(1-W)*FV*(EAF-ED))
20845 NEXT
20850 RETURN
27000 DIM TMEAN(365),ASSMN(365)
27010 INPUT "YOU WILL BE NEEDING TMAX,TMIN,ASS DATA FOR THE METHOD",Y$
27020 CHAIN MERGE "RDTHAV.SUB",27030,ALL
27030 GOTO 43000
27040 INPUT "DO YOU WANT TO START CALCULATION ?",Y$ : IF Y$ = "YES" THEN GOTO 27
060
27050 GOTO 27220
27060 I = PJUDA : J = HJUDA
27070 IF I > J THEN J = J + 365
27080 FOR DAY = I TO J
```

```
27090 K = DAY : IF K > 365 THEN K = K - 365
27100 LAMDA = 595 - 0.51 * TMEAN(K)
27110 XT = 0.017453*XLAT : Y = COS(0.01721421£*(K +192))
27120 DR = 0.40876*Y :SR = 1.00028 + 0.03269*Y
27130 Z = -TAN(XT)*TAN(DR) :ZAZ = SQR(1-Z^2)/2:IF Z>0 THEN GOTO 27135: AZ -3.141
592654£ + ATN(ZAZ)
27135 AZ = ATN(ZAZ)
27140 PSS = 7.63942*AZ :AR = AZ *SIN(XT)*SIN(DR)
27150 BR = COS(XT)*COS(DR)*SIN(AZ)/SR
27160 RA = 916.732*(AR+BR)
27170 RS = (0.25+0.5*ASSMN(K)/PSS)*RA/LAMDA * 10
27180 TMEANC = TMEAN(K)*9/5 + 32
27190 ETO(K) = 0.0075*TMEANC*RS
27200 PRINT "EVAPOTRANSPIRATION HR = "ETO(K);"JULIAN DAY ="K
27210 NEXT
27220 GOTO 379
35000 ISUM = 0
35010 FOR J= 1 TO 12
35020 IF MONTH = J THEN GOTO 35050
35030 ISUM = ISUM + MONTHX(J)
35040 NEXT J
35050 JUDA = ISUM + DATE
35060 RETURN
36000 ISUM = 0
36010 FOR J= 1 TO 12
36020 ISUM = ISUM + MONTH(J)
36030 IF JUDA <= ISUM THEN GOTO 36050
36040 NEXT
36050 DATE = JUDA - ISUM + MONTH(J)
36060 RETURN
52000 INPUT "ENTER THE STARTING MONTH AND DATE OF DATA ENTRY",SDMONTH,SDDATE
52010 INPUT "ENTER THE ENDING MONTH AND DATE OF DATA ENTRY",EDMONTH,EDDATE
52020 INPUT "Do you have a file name?",flnm$
52030 INPUT " For how many years do you have maximum and minimum temperature dat
a ?",NYR
52040 INPUT " Insert the maximum and minimum temperature data file disk ",Y$
52050 OPEN "I",1,flnm$
52060 SD = SDMONTH :ED = EDMONTH
52070 IF SDMONTH > EDMONTH THEN ED = ED +12
52080 FOR XMONTH = SD TO ED
52090 IF XMONTH > 12 THEN XMONTH = XMONTH - 12
52100 MONTH = XMONTH
52110 GOSUB 20000
52120 IF XMONTH = SDMONTH THEN L = SDDATE : GOTO 52140
52130 L = 1
52140 IF XMONTH = EDMONTH THEN M = EDDATE :GOTO 52160
52150 M = DAY
52160 FOR XDAY = L TO M
52170 MONTH = XMONTH : DATE = XDAY
52180 GOSUB 35000 : JUL = JUDA
52190 STMAX = 0 : STMIN = 0
52200 FOR XYEAR = 1 TO NYR
52210 INPUT £1, TMAX,TMIN:PRINT "YEAR="XYEAR;"MONTH="XMONTH;"DAY="XDAY;"JDAY="JU
L;"TMAX = "TMAX;"TMIN = "TMIN: STMAX =STMAX + TMAX :
 STMIN = STMIN + TMIN
52220 NEXT
52230 TMEAN(JUL)= (STMAX + STMIN)/(2*NYR):PRINT "TMEAN = "TMEAN(JUL):IF JUL = HJ
UDA THEN GOTO 52250
52240  NEXT : NEXT
52250 CLOSE
52251 H = HJUDA : IF PJUDA > H THEN H = H + 365
```

```
52252 OPEN "O",1,"TMEAN.DAT"
52253 FOR J = PJUDA TO H
52254 IF J > 365 THEN J = J-365
52255 WRITE £1,TMEAN(J): IF HJUDA = J THEN GOTO 52257
52256 NEXT
52257 CLOSE
52260 RETURN
53000 INPUT "ENTER THE STARTING MONTH AND DATE OF DATA ENTRY",SDMONTH,SDDATE
53010 INPUT "ENTER THE ENDING MONTH AND DATE OF DATA ENTRY",EDMONTH,EDDATE
53020 INPUT "Do you have a file name?",flnm$
53030 INPUT " For how many years do you have maximum and minimum humidity data ?
",NYR
53040 INPUT " Insert the maximum and minimum humidity data file disk ",Y$
53050 OPEN "I",1,flnm$
53060 SD = SDMONTH :ED = EDMONTH
53070 IF SDMONTH > EDMONTH THEN ED = ED +12
53080 FOR XMONTH = SD TO ED
53090 IF XMONTH > EDMONTH THEN XMONTH = XMONTH - 12
53100 MONTH = XMONTH
53110 GOSUB 20000
53120 IF XMONTH = SDMONTH THEN L = SDDATE : GOTO 53140
53130 L = 1
53140 IF XMONTH = EDMONTH THEN M = EDDATE :GOTO 53160
53150 M = DAY
53160 FOR XDAY = L TO M
53170 MONTH = XMONTH : DATE = XDAY
53180 GOSUB 35000 : JUL = JUDA
53190 SHMAX = 0 : SHMIN = 0
53200 FOR XYEAR = 1 TO NYR
53210 INPUT £1, RHMAX,RHMIN:PRINT "RHMAX = "RHMAX,"RHMIN = "RHMIN:IF JUL >= PJUD
A THEN SHMAX =SHMAX + RHMAX : SHMIN = SHMIN + RHMIN
53220 NEXT
53230 RHMEAN(JUL)= (SHMAX + SHMIN)/(2*NYR):PRINT "RHMEAN = "RHMEAN(JUL): IF JUL
= HJUDA THEN GOTO 53250
53240  NEXT : NEXT
53250 CLOSE
53260 RETURN
53500 INPUT "ENTER THE STARTING MONTH AND DATE OF DATA ENTRY ",SDMONTH,SDDATE
53510 INPUT "ENTER THE ENDING MONTH AND DATE OF DATA ENTRY ",EDMONTH,EDDATE
53520 INPUT "Do you have a file name?", flnm$
53530 INPUT " For how many years do you have velocity data ?",NYR
53540 INPUT "INSERT THE VELOCITY DATA DISK AND THEN PRESS RETURN/ENTER",Y$
53550 OPEN "I",1,flnm$
53560 SD = SDMONTH : ED = EDMONTH
53570 IF SDMONTH > EDMONTH THEN ED = ED + 12
53580 FOR XMONTH = SD TO ED
53590 IF XMONTH > EDMONTH THEN XMONTH = XMONTH - 12
53600 MONTH = XMONTH
53610 GOSUB 20000
53620 IF XMONTH = SDMONTH THEN L = SDDATE : GOTO 53640
53630 L = 1
53640 IF XMONTH = EDMONTH THEN M = EDDATE :GOTO 53660
53650 M = DAY
53660 FOR XDAY = L TO M
53670 SVEL = 0
53680 MONTH = XMONTH : DATE = XDAY
53690 GOSUB 35000 : JUL = JUDA
53700 FOR XYEAR = 1 TO NYR
53710 INPUT £1,VEL : PRINT "VEL= "VEL : IF JUL >= PJUDA THEN SVEL = SVEL + VEL
53720 NEXT
53730 VELMN(JUL) = SVEL/NYR :PRINT "VELMN = "VELMN(JUL):IF JUL = HJUDA THEN GOTO
```

```
 53750
53740 NEXT : NEXT
53750 CLOSE
53760 RETURN
54000 INPUT "ENTER THE STARTING MONTH AND DATE OF DATA ENTRY ",SDMONTH,SDDATE
54010 INPUT "ENTER THE ENDING MONTH AND DATE OF DATA ENTRY ",EDMONTH,EDDATE
54020 INPUT "Do you have a file name?", flnm$
54030 INPUT " For how many years do you have actual sunshine data ?",NYR
54040 INPUT "INSERT THE ACTUAL SUNSHINE DATA DISK AND THEN PRESS RETURN/ENTER",Y
$
54050 OPEN "I",1,flnm$
54060 SD = SDMONTH : ED = EDMONTH
54070 IF SDMONTH > EDMONTH THEN ED = ED + 12
54080 FOR XMONTH = SD TO ED
54090 IF XMONTH > 12 THEN XMONTH = XMONTH - 12
54100 MONTH = XMONTH
54110 GOSUB 20000:PRINT "day="DAY
54120 IF XMONTH = SDMONTH THEN L = SDDATE : GOTO 54140
54130 L = 1
54140 IF XMONTH = EDMONTH THEN M = EDDATE :GOTO 54160
54150 M = DAY
54160 FOR XDAY = L TO M
54170 SASS = 0
54180 MONTH = XMONTH : DATE = XDAY
54190 GOSUB 35000 : JUL = JUDA
54200 FOR XYEAR = 1 TO NYR
54210 INPUT £1,ASS : PRINT "YEAR ="XYEAR;"MONTH="XMONTH;"DAY="XDAY;"JDAY="JUL;"A
SS= "ASS : IF JUL >= PJUDA THEN SASS = SASS + ASS:PR
INT "SASS="SASS;"PJUDA="PJUDA
54220 NEXT
54230 ASSMN(JUL) = SASS/NYR :PRINT "ASSMN = "ASSMN(JUL):IF JUL = HJUDA THEN GOTO
 54250
54240 NEXT : NEXT
54250 CLOSE
54260 RETURN
```

```
IS THE GROWING YEAR IS A LEAP YEAR ?
WHAT IS THE LATITUDE AND ELEVATION OF YOUR AREA ? 24.2  10
WHAT IS THE NAME OF THE CROP ?TRANSPLANTED AMAN
WHAT IS THE PLANTING MONTH AND DATE FOR TRANSPLANTED AMAN
[ENTER MONTH AS THE SERIAL NO 1 FOR JANUARY AND THEN ENTER DATE SEPARATED BY A C
OMMA] 7  1
WHAT IS THE HARVESTING MONTH AND DATE FOR TRANSPLANTED AMAN  10  18
HOW MANY GROWTH PERIODS ARE THERE ? 6
HOW MANY DAYS BETWEEN GROWTH PERIOD- 1  AND GROWTH PERIOD- 2  ARE THERE AND WHAT
 IS THE RESPECTIVE CROP SUCCEPTIBILITY FACTOR ? 45
 0.28
HOW MANY DAYS BETWEEN GROWTH PERIOD- 2  AND GROWTH PERIOD- 3  ARE THERE AND WHAT
 IS THE RESPECTIVE CROP SUCCEPTIBILITY FACTOR ? 5
 0.4
HOW MANY DAYS BETWEEN GROWTH PERIOD- 3  AND GROWTH PERIOD- 4  ARE THERE AND WHAT
 IS THE RESPECTIVE CROP SUCCEPTIBILITY FACTOR ? 30
 0.48
HOW MANY DAYS BETWEEN GROWTH PERIOD- 4  AND GROWTH PERIOD- 5  ARE THERE AND WHAT
 IS THE RESPECTIVE CROP SUCCEPTIBILITY FACTOR ? 10
 0.59
HOW MANY DAYS BETWEEN GROWTH PERIOD- 5  AND GROWTH PERIOD- 6  ARE THERE AND WHAT
 IS THE RESPECTIVE CROP SUCCEPTIBILITY FACTOR ? 20
 0.44
 WHAT IS THE DIKE HEIGHT IN MM ? 150
 WHAT IS THE SATURATED MOISTURE CONTENT IN HEIGHT OF WATER IN MM ? 150
WHAT IS THE MINIMUM HEIGHT OF WATER FOR STRESS DEVELOPMENT ? 120
 WHAT IS THE FIELD CAPACITY OF THE SOIL ? 120
 WHAT IS THE PERCOLATION UNDER SATURATED CONDITION ? 6
 HAVE YOU APPLIED ANY SUPPLIMENTARY IRRIGATION ?
 DO YOU HAVE EVAPORATION DATA ?
 DO YOU WANT TO ENTER EVAPOTRANSPIRATION DIRECTLY ?
 DO YOU WANT TO ESTIMATE EVAPOTRANSPIRATION BY HARGRIEVES METHOD ?YES
I =  1  N(I) = 45 SD(I) =  0 Cs(I) = 0.28 SDI =  0
I =  2  N(I) = 5 SD(I) =  0 Cs(I) = 0.4 SDI =  0
I =  3  N(I) = 30 SD(I) =  0 Cs(I) = 0.48 SDI =  0
I =  4  N(I) = 10 SD(I) =  0.1 Cs(I) = 0.59 SDI =  0.059
I =  5  N(I) = 20 SD(I) =  0.15 Cs(I) = 0.44 SDI =  0.125
YEILD SIMULATION MODEL FOR RICE
 THE MODEL IS RUNNING FOR THE CROP TRANSPLANTED AMAN
PLANTING DATE = 182   RELATIVE YEILD = 87.5 %
```

MONTH	DAY	VEL	ASS	TMEAN	RHMN	RAIN	BT(O)
JUL	1	7.000	4.791	29.073	87.045	2.091	4.040
JUL	2	5.727	4.573	29.059	83.000	6.545	3.905
JUL	3	4.636	6.182	29.095	80.818	6.545	4.904
JUL	4	5.364	6.627	29.786	81.682	4.364	5.259
JUL	5	4.364	4.891	29.768	81.773	0.727	4.167
JUL	6	5.727	7.100	29.736	82.773	3.545	5.550
JUL	7	5.364	7.073	29.100	82.273	2.364	5.456
JUL	8	7.182	6.955	29.164	85.182	4.000	5.391
JUL	9	5.636	7.455	29.245	83.818	8.364	5.711
JUL	10	5.364	6.300	29.159	85.864	4.636	4.985
JUL	11	3.909	6.018	29.377	86.500	8.727	4.834
JUL	12	4.818	5.373	28.941	86.727	12.182	4.390
JUL	13	4.364	4.627	29.686	85.682	7.091	3.996
JUL	14	6.545	3.845	29.082	86.318	11.000	3.459
JUL	15	5.182	3.064	29.005	121.636	11.727	2.970
JUL	16	5.455	2.364	27.941	87.545	22.545	2.478
JUL	17	4.909	3.127	27.609	89.273	20.182	2.917
JUL	18	3.545	5.127	27.814	87.091	11.000	4.133
JUL	19	4.727	4.682	28.505	87.455	6.091	3.926
JUL	20	4.364	5.627	28.814	84.318	4.636	4.534
JUL	21	3.727	4.564	29.100	87.864	13.909	3.905
JUL	22	2.909	2.964	28.791	87.955	24.636	2.895
JUL	23	4.818	2.982	29.259	85.136	6.273	2.937
JUL	24	5.909	5.173	29.236	85.136	7.364	4.295
JUL	25	5.273	4.691	29.009	85.455	8.455	3.975
JUL	26	5.364	5.564	28.973	88.045	10.545	4.510
JUL	27	5.727	3.000	28.795	87.455	17.182	2.917
JUL	28	4.000	3.891	28.505	88.136	19.455	3.442
JUL	29	4.909	4.518	28.427	85.500	20.909	3.817
JUL	30	4.636	4.073	29.000	85.227	3.545	3.591
JUL	31	5.545	3.491	28.877	85.955	2.727	3.223
AUG	1	4.182	6.645	28.432	83.591	8.182	5.109
AUG	2	4.273	6.173	29.305	82.045	2.182	4.915
AUG	3	4.727	6.627	29.318	77.818	0.909	5.197
AUG	4	9.000	6.109	29.055	82.545	1.636	4.846
AUG	5	6.182	4.273	29.127	86.682	5.818	3.719
AUG	6	5.818	4.609	28.777	86.864	16.636	3.895
AUG	7	5.636	5.264	28.514	86.227	19.364	4.269
AUG	8	6.273	6.736	28.655	85.591	9.636	5.178
AUG	9	4.364	6.173	29.018	82.773	6.182	4.872
AUG	10	3.545	5.618	29.382	82.864	4.818	4.566
AUG	11	3.636	5.373	29.150	83.318	6.727	4.389
AUG	12	6.273	6.964	29.655	82.045	1.091	5.425
AUG	13	5.000	7.482	29.068	84.455	10.273	5.670
AUG	14	6.182	6.700	29.105	81.727	7.727	5.191
AUG	15	6.818	4.582	28.655	85.182	17.727	3.850
AUG	16	6.091	4.745	28.182	87.000	44.818	3.905
AUG	17	4.273	6.464	29.014	85.955	4.182	5.025
AUG	18	4.000	6.536	28.577	86.273	12.909	5.016
AUG	19	4.636	4.073	28.200	86.818	13.636	3.494
AUG	20	3.364	5.600	28.645	85.227	8.727	4.449
AUG	21	3.364	4.364	29.077	84.045	8.364	3.734
AUG	22	3.909	6.409	29.518	82.727	5.182	5.025
AUG	23	4.727	4.864	29.232	82.818	0.545	4.045

AUG	24	3.000	3.700	29.527	82.909	5.273	3.353
AUG	25	3.909	4.745	29.355	86.182	3.182	3.975
AUG	26	5.818	7.173	29.632	80.591	8.545	5.483
AUG	27	6.000	5.591	28.868	82.273	2.727	4.432
AUG	28	6.273	4.855	29.259	84.136	1.909	4.018
AUG	29	4.182	5.555	28.323	85.636	21.364	4.345
AUG	30	4.182	3.855	28.782	82.227	3.545	3.366
AUG	31	4.455	4.418	28.432	80.955	7.000	3.669
SEP	1	6.273	7.418	28.918	84.227	6.909	5.500
SEP	2	6.545	5.373	29.286	82.955	2.182	4.304
SEP	3	6.000	4.945	29.177	84.318	5.909	4.030
SEP	4	5.273	4.818	28.864	84.364	11.000	3.920
SEP	5	4.909	6.845	29.059	83.136	4.273	5.139
SEP	6	4.909	4.773	29.123	83.727	5.909	3.901
SEP	7	4.000	6.845	29.273	82.000	8.909	5.145
SEP	8	3.909	7.691	29.541	81.864	3.273	5.673
SEP	9	6.091	6.836	28.664	82.545	9.636	5.051
SEP	10	4.927	3.791	28.686	84.773	12.818	3.259
SEP	11	3.818	5.382	28.605	85.091	6.818	4.174
SEP	12	4.364	4.964	28.295	83.136	7.182	3.895
SEP	13	3.364	6.573	28.614	83.864	10.273	4.849
SEP	14	2.636	6.227	28.650	84.773	8.364	4.642
SEP	15	3.818	5.218	28.632	83.636	6.909	4.045
SEP	16	5.000	5.200	28.373	83.227	13.000	4.002
SEP	17	3.273	7.755	29.032	80.909	5.364	5.536
SEP	18	2.727	8.718	29.459	79.545	2.364	6.138
SEP	19	2.818	7.827	29.664	79.318	4.182	5.628
SEP	20	3.091	8.536	29.950	81.000	1.000	6.066
SEP	21	3.727	8.655	30.527	81.727	1.818	6.196
SEP	22	3.182	7.373	29.714	82.955	9.727	5.324
SEP	23	3.000	6.955	28.832	81.182	7.364	4.969
SEP	24	3.182	8.718	28.795	81.136	7.364	5.951
SEP	25	3.909	6.427	29.436	83.318	13.091	4.705
SEP	26	4.182	6.736	29.064	82.227	7.182	4.828
SEP	27	3.000	7.782	29.005	82.773	20.000	5.397
SEP	28	4.091	6.000	28.591	81.864	26.000	4.337
SEP	29	8.091	5.409	28.673	85.773	7.455	4.002
SEP	30	10.000	4.182	28.455	84.682	23.091	3.291
OCT	1	3.000	4.873	28.645	84.864	15.636	3.677
OCT	2	2.636	6.745	28.073	81.773	4.364	4.638
OCT	3	2.909	6.209	28.359	84.727	10.182	4.360
OCT	4	2.727	6.873	28.314	82.409	6.455	4.702
OCT	5	2.545	8.533	28.650	81.318	6.182	5.628
OCT	6	2.909	6.018	28.805	82.773	1.000	4.254
OCT	7	3.545	6.682	28.736	82.636	2.000	4.594
OCT	8	2.909	7.282	28.595	82.727	5.727	4.887
OCT	9	2.909	8.045	28.864	82.591	3.364	5.312
OCT	10	2.455	9.864	28.614	80.545	1.091	6.239
OCT	11	2.091	9.455	28.305	78.000	6.909	5.956
OCT	12	2.636	9.164	28.327	75.773	3.091	5.783
OCT	13	2.818	8.573	28.350	77.955	6.455	5.453
OCT	14	2.636	9.645	28.291	79.545	1.636	5.988
OCT	15	1.727	10.064	28.441	76.000	1.455	6.205
OCT	16	2.455	10.255	28.373	75.909	0.545	6.271
OCT	17	2.545	10.000	27.959	75.773	0.364	6.058
OCT	18	2.818	8.527	27.909	78.136	1.000	5.273
OCT	19	2.818	8.927	27.395	0.000	0.000	0.000
OCT	20	3.000	8.527	27.809	0.000	0.000	0.000
OCT	21	3.455	8.627	27.486	0.000	0.000	0.000
OCT	22	3.000	8.982	27.382	0.000	0.000	0.000