*Southeast Asian Studies,* Vol. 23, No. 1, June 1985

# A Model for the Assessment of Rainfed Agriculture in Thailand

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## Abstract

A general model consisting of three submodels for daily rainfall generation, daily evapotranspiration estimation, and daily water balance computation, respectively, was developed in this study for the assessment of rainfed agriculture in Thailand. It can be used to obtain the information on important factors related to rainfed agriculture such as the number of stress days with their frequency and period of occurrence, the amount of supplementary water requirement and drainage requirement. Through simulation runs made by shifting assumed planting dates, one may arrive at the most suitable planting period for each crop.

## Introduction

In many countries in Southeast Asia rainfed agriculture is still widely practiced. The national economies of these countries depend heavily on the agricultural production, which in turn depends largely on the distribution of rainfall in space and time. To improve the agricultural production, it is desirable to make full use of the amount of available water, possibly by shifting the planting dates of the economic crops to avoid the frequent occurrence of stress conditions or waterlogging. In order to help in the selection of these planting dates, it is important that the effect of them be evaluated in a quantitative manner. Such an evaluation would be enhanced and conveniently carried out with the use of a mathematical model which takes into account the important factors of rainfed agriculture. The main purpose of this study is to develop that needed model.

In Thailand, the work related to rainfed agriculture may be considered to have started in 1974 with a study made by the Mekong Secretariat [1974], where a simple model was developed for Northeastern Thailand. This was followed by two consecutive studies made by the Asian Institute of Technology [AIT 1978; 1981] for the same region (see also Phien and Sunchindah [1981] and Phien [1983]). The model developed in 1981 consists of a Markov chain model for daily rainfall generation and the Jensen-Haise formula for estimating daily evapotranspiration. The model was later applied [AIT 1983], with some minor modifications, to several areas carefully selected throughout Thailand in order to evaluate the potential success of important economic crops under rainfed conditions. It is modified again in

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this study to make it more comprehensive.

## Model Development

Three important processes which involve in the development of a crop, viewed macroscopically, are the rainfall, evapotranspiration and water movement in the field. The mathematical model being attempted should properly combine these components. It should be noted that for the effect of shifting planting dates of a crop to be clearly seen, a *daily basis* is used, because a longer time period would not be able to reveal all the changes in the occurrence and severity of drought conditions. Therefore, all the three components are modelled on a daily basis in this study.

### *Rainfall Component*

A mathematical model is needed for the generation of daily rainfall data. To this aim, three different models have been developed at AIT. These are, respectively, the Markov chain model with seven states [Phien and Warakittimalee 1981], the Markov chain model with two states [Phien and Lukkananukul 1981], and the model based upon the method of fragments [Balmadres 1983]. Even though Balmadres found that the model based on the method of fragments is relatively superior to the others, it is not suitable for use in the present work, because the generation scheme involved in that model produces more data than needed. Consequently, the Markov chain model with two states where rainfall amounts on wet days are represented by a shifted lognormal distribution was employed in this study because it is better than the model with seven states [Phien 1982]. The generation procedure is as follows:

(1) For each month, the transition probabilities and the parameters of the lognormal distribution are estimated. In this case, the transition matrix can be conveniently expressed as:

$$P=\begin{bmatrix} a & 1-a \\ b & 1-b \end{bmatrix} \tag{1}$$

$$\begin{aligned} &\text{where} \quad a=\text{Prob (dry day/dry day)} \\ &\text{and} \quad b=\text{Prob (dry day/wet day)} \end{aligned} \tag{2}$$

Using the historical data, these parameters can be easily estimated according to the method of maximum likelihood:

$$\begin{aligned} a&=f_{11}/(f_{11}+f_{12}) \\ b&=f_{21}/(f_{21}+f_{22}) \end{aligned} \tag{3}$$

where $f_{ij}$ (i, j=1, 2) denotes the historical frequency of transitions from state i to state j in the daily values. It should be noted that the dry state corresponds to all daily rainfall amounts $\leq 1$ mm while the wet state corresponds to daily amounts $>1$ mm as defined previously [AIT 1981]. Likewise, the parameters of the lognormal distribution can be estimated as:

$$\mu=\frac{1}{n}\sum \ln(x-x_0) \tag{4}$$

$$\sigma^2=\frac{1}{n}\sum [\ln(x-x_0)-\mu]^2 \tag{5}$$

in which n is the number of days with rainfall amount $x>x_0=1$ mm in that month, and the sum extends all over the n values.

(2) A uniform number U between 0 and 1 is then generated.

(3) Knowing the state i of one day (i=1 for a dry day, i=2 for a wet day), the state

j of the following day is determined by comparing U with a for $i=1$, or with b for $i=2$, respectively. If $U \leq a$ (or b), the following day is dry and hence $j=1$; otherwise $j=2$.

(4) If $j=1$ (the following day is dry) the rainfall amount on that day is set equal to zero. If $j=2$, it is a wet day; a lognormal variable X with parameters $\mu$ and $\sigma$ is generated, and the rainfall amount is computed by:

$$R=X+x_0 \qquad (6)$$

Steps (2) through (4) are repeated after setting $i=j$, until the desired length of generated sequence is reached.

It is clear that the state and the rainfall amount on the first day must be determined first. This may be done as follows:

Let q denote the probability that the first day is dry, then q may be estimated according to the following equation:

$$q=F_1/(F_1+F_2) \qquad (7)$$

where $F_i$ $(i=1, 2)$ is the historical frequency of rainfall amounts on the first day being in state i. Having obtained q, the state and rainfall amount of the first day are determined as follows:

(a) Generate a uniform random number V on (0, 1).

(b) Compare V with q. If $V \leq q$ then the first day is dry $(i=1)$ and the rainfall is set equal to zero. Otherwise (i.e., if $V>q$), the first day is wet $(i=2)$, and the rainfall amount is obtained as presented in step (4) with $j=2$.

### *Potential Evapotranspiration Component*

The evapotranspiration can be computed as the product of the potential evapotranspiration with a coefficient to be defined later. So a method of estimating the potential evapotranspiration must be selected.

There exist several methods for the estimation of potential evapotranspiration (PET), but those described by Doorenbos and Pruitt [1977] have become increasingly popular. Since the Blaney-Criddle method should be used for periods no shorter than one month [*ibid.*: 4], it is not suitable for the present work where a daily basis was adopted. The radiation method requires the use of solar radiation or sunshine duration data which are not available for most meteorological stations in Thailand. Moreover, when solar radiation or sunshine radiation data are available at a station, the other data required by the Penman method are also available. In such case, the Penman method is used instead because it is commonly believed to to provide most reliable estimates. Thus only two methods, namely the Penman and Pan Evaporation methods, were employed in this study with the second one being more applicable because the data needed are available at many areas. These are briefly described in the following.

#### Penman Formula

There have been many modifications of the Penman formula. In this study, the following equation is used:

$$PET=C[w*Rn+(1-w)*f(u) *(e_a-e_d)] \qquad (8)$$

where: w =a weighting factor

Rn =net radiation in equivalent evapotranspiration (mm/day)

f(u) =wind function

$e_a-e_d$ =difference between the saturation vapor pressure at mean air temperature and actual vapor pressure, respectively, and

$C$ =adjustment factor to compensate for the effect of day and night weather conditions.

(a) The weighting factor w depends on temperature and altitudes, with typical values given in Doorenbos and Pruitt [*ibid.*: 13].

(b) The net radiation (Rn) can be measured but such data are seldom available. It is commonly calculated from solar radiation (or sunshine duration), temperature and humidity data by the following equation:

$$Rn = Rns - Rnl \qquad (9)$$

where: Rns = net short-wave radiation, and
Rnl = net long-wave radiation.

The net short-wave radiation can be obtained from the measured solar radiation (Rs) by:

$$Rns = (1-\alpha)Rs$$

with $\alpha = 0.25$. The net long-wave can be computed as follows:

$$Rnl = (0.34 - 0.044e_d^{\frac{1}{2}})\,(0.1 + 0.9n/N)\Psi(T) \qquad (10)$$

in which $\Psi(T)$ is a function of temperature, with values given in Doorenbos and Pruitt [*ibid.*: Table 14, 27].

(c) The wind function expresses the effect of wind on PET and can be written as:

$$f(u) = 0.2(1 + U_2/100) \qquad (11)$$

where $U_2$ is the 24-hr wind run in km/day at 2 m high.

(d) The adjustment factor C may be obtained also from the same report [*ibid.*: Table 16, 28].

Pan Evaporation Method

The relationship recommended by Doorenbos and Pruitt [*ibid.*] can be written as:

$$PET = Kp * EP \qquad (12)$$

where Kp is the pan coefficient and EP represents the pan evaporation in mm/day. The values of the pan coefficient may be obtained from Doorenbos and Pruitt [*ibid.*: Tables 18 and 19, 34].

### *Water Balance Component*

The water balance model employed in this study was modified from that developed by AIT [1981] in an attempt to make it more realistic. The most important modification was the introduction of the two water depths corresponding respectively to the saturation and field capacity. The important factors of the model are redefined in the following:

*Water Depth at Saturation* (*WDS*). This water depth varies with the crop and soil characteristics and may be estimated by the equation:

$$WDS = f * B * D/100 \qquad (13)$$

where f is the porosity (or total pore space, in percentage), B is the apparent gravity and D is the depth of root zone (mm).

*Water Depth at Field Capacity* (*WDFC*). Like the WDS, this water depth varies with the soil characteristics. It may be estimated as follows:

$$WDFC = FC * B * D/100 \qquad (14)$$

where FC is the field capacity in percentage. For definition and typical values see Hansen *et al.* [1979].

*Upper Limit of Water Depth* (*UP*). This limit is introduced in order to determine the maximum water depth allowed to be stored on the ground surface. All the excess water will overflow.

For paddy fields, the maximum standing water, denoted by DMAX, is assumed to be 150 mm as in AIT [1983]. The upper limit for water depth in this case is given by:

$$UP = WDS + 150 \text{ (mm)} \quad (15)$$

where WDS is given by eq. 13.

For upland crops, no standing water is assumed (DMAX=0 mm), and the upper limit is set equal to the equivalent water depth at saturation:

$$UP = WDS \quad (16)$$

*Lower Limit of Water Depth (DMIN).* This concept is needed in the definition of stress day (to be given). It indicates the level at which the crop starts to respond to the shortage of soil moisture. As an approximation, it is defined as follows (Figs. 1 and 2):

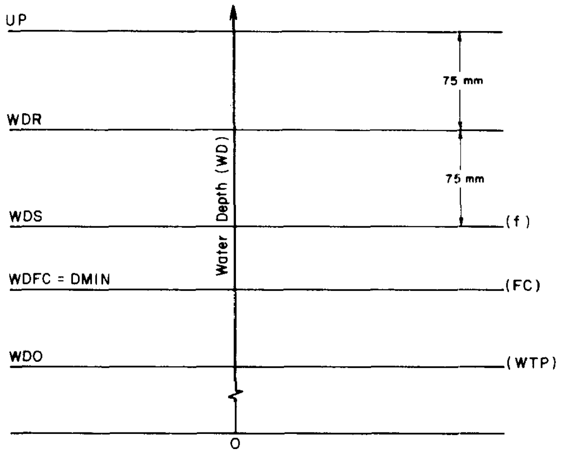

**Fig. 1** Definition Sketch for Water Depth Computation (Paddy)

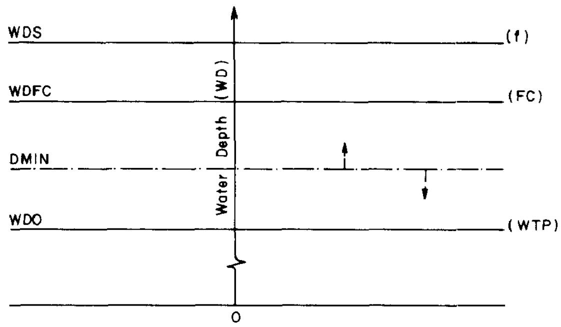

**Fig. 2** Definition Sketch for Water Depth Computation (Upland Crops)

for paddy: $DMIN = WDFC \quad (17)$

(simplified from Wickham [1975: 158])

for upland crops: a dynamic approach is used in this study in the definition of the lower limit. Mathematically, it is written as:

$$DMIN = [FC - p*(FC - WTP)] *B*D/100 \quad (18)$$

where p is a fraction of available soil water and WTP is the permanent wilting point with values (in percentage) obtained from Hansen *et al.* [1979]. The value of p is estimated as recommended by Doorenbos and Pruitt [1977]. It should be noted that since p varies with the atmospheric evaporative demand, and the depth of the root zone (D) in eq. 18 varies with the growth stage, DMIN is not fixed. If the water depth corresponding to the permanent wilting point is denoted by WDO, i.e.:

$$WDO = WTP*B*D/100$$

then eq. 18 can be rewritten as:

$$DMIN = pWDO + (1-p)*WDFC \quad (19)$$

*Deep Percolation (DPER).* For paddy, deep percolation occurs when there is water stored on the ground surface. It may be assumed to be constant for each soil. In this study, it is set equal to 3 mm/day for sandy loam [Adhikary 1979] and 1 mm/day for clay. For upland crops, deep percolation is neglected, i.e., DPER=0.

*Stress Days.* Again as an approximation, a stress day is defined as a day when the water depth is less than DMIN.

The water balance computation is carried out by first computing tentatively the water depth (WD) on day k:

$$WD_k = WD_{k-1} + R_k - ET_k - PER_k \qquad (20)$$

where $WD_k$, $R_k$, $ET_k$ and $PER_k$ are respectively the water depth, rainfall, evapotranspiration, and percolation on that day. The value of percolation water is computed as follows:

$$PER_k \begin{cases} =0 & \text{if } WD_{k-1} \leq WDS \\ =DPER & \text{if } WD_{k-1} > WDS \end{cases} \qquad (21)$$

The computation of the evapotranspiration (ET) will be considered later on at the end of this section.

After the tentative computation according to eq. 20, there are three possibilities to account for:

(1) *If $WD_k > UP$*, overflow will take place. The overflow water (OFL) is then computed as:

$$OFL_k = WD_k - UP \qquad (22)$$

Afterwards the water depth is set equal to the upper limit:

$$WD_k = UP$$

Correspondingly, the effective rainfall (ER) on that day is computed from:

$$ER_k = WD_k - WD_{k-1} + ET_k + PER_k \qquad (23)$$

(2) *If $DMIN \leq WD_k \leq UP$*, the tentative water depth in eq. 20 becomes the actual depth for day k. In this case:

$$ER_k = R_k \text{ and } OFL_k = 0 \qquad (24)$$

(3) *If $WD_k < DMIN$*, day k is a stress day:

$$ER_k = 0 \text{ and } OFL_k = 0$$

The drainage requirement (DR) is computed as the sum of the overflow and percolation:

$$DR_k = OFL_k + PER_k \qquad (25)$$

The water balance computation as described is carried out day-after-day so that the carry-over effect can be accounted for.

*Computation of Evapotranspiration.* The actual daily evapotranspiration (ET) depends upon the availability of soil water, and decreases as the depletion increases. It is computed from the daily potential evapotranspiration (PET) by the equation:

$$ET = Ck * PET \qquad (26)$$

where Ck is a coefficient which is expressed in terms of the crop coefficient (Kc) and the stress coefficient (Ks) as follows:

$$Ck = Kc * Ks \qquad (27)$$

There exist several formulas for computing Ks (see Boonyatharokul and Walker [1979]). In this study, the popular linear form is used with the following simple modification:

$$\text{if } WD \geq DMIN: \quad Ks = 1 \qquad (28)$$

$$\text{if } WDO \leq WD \leq DMIN:$$

$$Ks = \frac{WD - WDO}{DMIN - WDO} = 1 - \frac{DMIN - WD}{DMIN - WDO} \qquad (29)$$

Clearly, with this definition, Ks indicates the severity of stress conditions. It is equal to 1 when the day is not a stress day, and equal to 0 when the water depth reaches that at the permanent wilting point.

The atmospheric evaporative demand of a crop at a growth stage is represented by ETcrop, which is defined as:

$$ETcrop = Kc * PET \qquad (30)$$

The value of ETcrop is used in the determination of p, the fraction of available soil water as suggested by Doorenbos and Pruitt [1977].

With this definition, the actual daily evapotranspiration, eq. 26, can be rewritten as:

$$ET = Ks * ETcrop \tag{31}$$

*Computation of Supplementary Irrigation Water.* When a stress day occurs ($WD < DMIN$) and under the assumption that water is available, the amount of supplementary requirement (SWR) is computed by the equation:

$$SWR = WDR - WD \tag{32}$$

The water depth requirement (WDR) is defined as follows:

For paddy:

$$WDR = WDS + 75 \text{ (mm)}$$

For upland crops:

$$WDR = WDFC \tag{33}$$

(In Thailand, the standing water required is observed to be approximately equal to 75 mm).

*Remarks*

(i) The water balance computation presented above does not take into account the water coming from other fields. It is consequently applicable to rather flat and large areas only.

(ii) The amount of water due to capillary force from the soil layers underneath the root zone is neglected in this study in conformity with the simplified scheme adopted in the water balance computation.

(iii) The drainage requirement (DR) for paddy fields is modified for the last two weeks of the growing season. During this period, all the standing water on the ground surface must be drained because it is no longer useful. This is also intended to keep the paddy fields dry for harvesting.

(iv) The depth of the root zone (H) is assumed to vary with time for upland crops. During the first 10 days, it is set equal to 5 cm, then is increased linearly to the full length at the end of the third stage, and remains constant afterwards.

(v) Immediately following a rainfall or an irrigation, there will be additional evaporation from the soil surface [Kincaid and Heerman 1974]. However, this part is neglected in the present study.

## The Simulation Work

In the overall simulation, the rainfall generation model is used to provide the value of daily rainfall on any day of the growing season. Similarly, the daily evapotranspiration is estimated. Finally the water balance model is applied in order to determine the important factors related to rainfed agriculture, namely stress day, drainage requirement, effective rainfall and supplementary water. In reality, rainfall data and other meteorological data are available for different periods. For example, reliable rainfall data are available in many stations since 1952, while most pan evaporation data are available for much shorter periods (see Anukularmphai *et al.* [1980]). If the actual data of all meteorological factors involved were used, then their records would be cut short to the same overlapping period; this obviously reduces the length of the existing data of other factors. This shortening is not desirable in any statistical analysis. In order to overcome this situation, simulation models can be used. For rainfall, the model presented previously is intended for this purpose. Another scheme for generating daily potential evapotranspiration is needed. In the following, all details related to the simulation work are described whereby the relevance and suitability of the presented scheme can be seen.

*Daily Rainfall Simulation*

The overall simulation is applied to different crops with the differing growth seasons. This means that the starting day and starting month may vary from crop to crop. If the historical data are read in when the rainfall model is used, the computer time and computer storage needed will be unnecessarily large. In fact the historical record is needed only for the estimation of the model parameters, namely a, b, $\mu$, $\sigma$ and q. Consequently, it is read in only once and these parameters are estimated. Only the estimated values for all the 12 months are stored for later use.

In the rainfall generation model, uniform random numbers on (0, 1) and lognormal variables are used. There have been many random number generators of which the best may be that proposed by Wichmann and Hill [1982]. This generator is used in the present work.

The lognormal variables can be generated by first producing normal variables and then by applying the exponential function. Standard normal variables can be conveniently generated by the method of Box and Muller [1958]:

$$Z=(-2\ln U)^{\frac{1}{2}}\cos(2\Pi V)\quad [\text{or } \sin(2\Pi V)]$$

where U and V are two uniform random numbers on (0, 1). The lognormal variable X with parameters $\mu$ and $\sigma$ is obtained as:

$$X=\exp(\sigma Z+\mu)$$

*Simulation of Daily Potential Evapotranspiration*

As mentioned before, the Penman and Pan Evaporation methods were used for the estimation of PET, depending upon availability of the data required. The simulation procedures are now described accordingly.

Penman Method

Since a number of meteorological factors involve in this approach, all the corresponding data should be read in once and the values of PET are computed. This means that all the historical data required in the estimation are used and the result comprises the estimated values of PET.

In the overall simulation, however, due to the reason mentioned at the beginning of this section, the estimated values (treated as historical data) cannot be used directly. Instead, they are used to estimate the parameters of the model which is built to generate PET. Such a model may be readily obtained by following the scheme of Thomas and Fiering [1962]. The resulting generation model can reproduce the mean, standard deviation and serial correlation coefficient of daily values. It can be written as:

$$PET_k=\overline{PET}_k+b_k(PET_{k-1}-\overline{PET}_{k-1})+S_k(1-r_k^2)^{\frac{1}{2}}Z_k \qquad (34)$$

where $PET_k$ is the potential evapotranspiration on day k;

$\overline{PET}_k$ and $S_k$ are the mean and standard deviation of the historical values of PET on day k,

$r_k$ is the correlation coefficient between the historical PET data on days k and k−1,

$b_k=r_kS_k/S_{k-1}$, and

$Z_k$ is a variable with zero mean and unit standard deviation.

As commonly practiced, $Z_k$ is considered as a standard normal variable in this study.

In order to conform with the fact that only one transition matrix is used for each month in the rainfall generation model, all $r_k$ are replaced by their average value:

$$r=\frac{1}{m}\sum_{k=1}^{m} r_k$$

where m is the total number of $r_k$ in the month under consideration. With this simplification, eq. 34 becomes:

$$PET_k=\overline{PET}_k+rS_k(PET_{k-1}-\overline{PET}_{k-1})/S_{k-1}+S_k(1-r^2)^{\frac{1}{2}}Z_k \qquad (35)$$

The parameters $\overline{PET}_k$, $S_k$ and r are stored for each month of the year instead of all the values of PET estimated from the related historical meteorological data.

Pan Evaporation Method

As seen from eq. 12 the values of PET in this case can be obtained directly from the historical record of pan evaporation (EP). Once the values of PET have been estimated, the parameters $\overline{PET}_k$, $S_k$ and r can be estimated and stored for use in the simulation using the Thomas-Fiering model. Another way to generate PET values is first to use the Thomas-Fiering model in producing values for EP, and then multiply them by Kp to get the values for PET. In this case, the equation involved is as follows:

$$EP_k=\overline{EP}_k+s_k(EP_{k-1}-\overline{EP}_{k-1})/s_{k-1}+s_k(1-\rho^2)^{\frac{1}{2}}z_k \qquad (36)$$

where $EP_k$ is the pan evaporation on day k,

$\overline{EP}_k$ and $s_k$ are respectively the mean and standard deviation of the historical pan evaporation on day k,

$z_k$ is a standard normal variable, and

$$\rho=\frac{1}{m}\sum_{k=1}^{m}\rho_k$$

$\rho_k$ being the correlation coefficient between the historical values of EP on days k and k−1.

From eq. 12, if PET with values computed from pan evaporation data is generated by eq. 35, and EP is generated by eq. 36, then the following relationships hold:

$$\overline{PET}_k=Kp\,\overline{EP}_k$$
$$S_k=Kp\,s_k$$
$$r=\rho$$

As in the previous method, the parameters $\overline{EP}_k$, $s_k$ and $\rho$ are stored instead of the historical record of EP itself.

*Remark*

Since $PET_k$ or $EP_k$ cannot be negative, when a negative value is generated, it is set equal to the mean, viz.

$$\text{if } PET_k\leq 0, \text{ set } PET_k=\overline{PET}_k$$
$$EP_k\leq 0, \text{ set } EP_k=\overline{EP}_k$$

*Water Balance Computation*

(1) Crop Coefficient

The determination of actual evapotranspiration from potential evapotranspiration requires knowledge of a proportionality factor called crop coefficient (Kc). It varies from crop to crop and also from growth stage to growth stage. Generally, the growing season of paddy and upland crops can be divided into three stages and four stages, respectively. The crop coefficient for each growth stage is then obtained by the method presented by Doorenbos and Pruitt [1977].

(2) Depth of Root Zone

Attempts have been made to collect the field data on root zone for the crops under consideration. However, no clear pattern could be identified. Consequently the general values suggested by Doorenbos and Pruitt [*ibid.*] for different crops are used in this work. For each crop, the values for different soils are determined from the maximum and minimum values where the maximum value is assigned to sandy loam, minimum value to clay. The depths for clay loam are computed according to the following equation:

$$\text{D(clay loam)} = \text{D(clay)} + [\text{D(sandy loam)} - \text{D(clay)}]/3$$

When actual data available, the estimated maximum and minimum values are adjusted

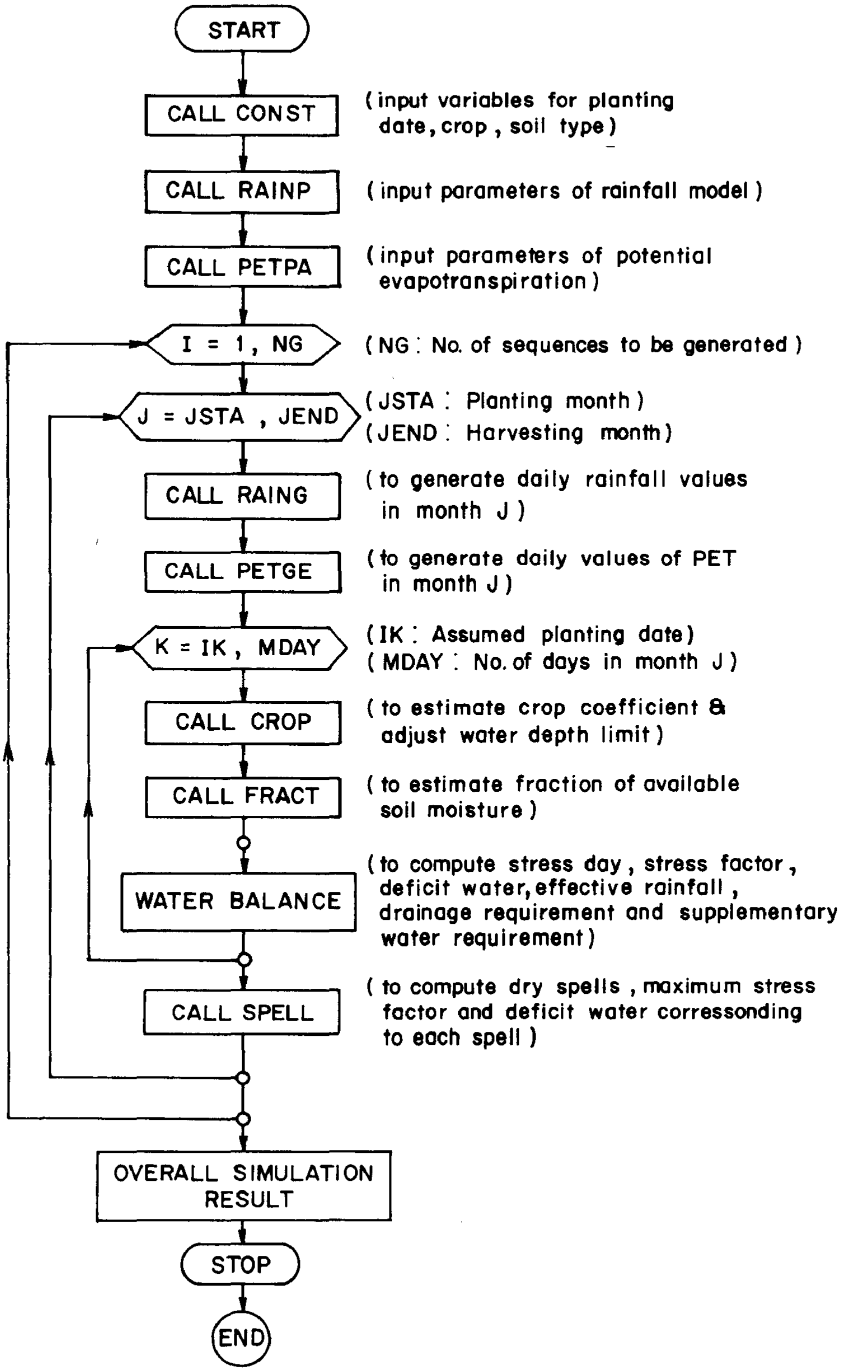

**Fig. 3** Flow Chart of the Overall Simulation Scheme

accordingly.

*Remark*

For several provinces, there are many soil series of which the most popular ones are the Pak Chong and Chok Chai series, especially in the Northeast. The general values of soil characteristics provided by Hansen *et al.* [1979] are adjusted using the actual data provided by Kubota *et al.* [1979].

### (3) Decision Factors in the Simulation Work

With detailed information presented in the foregoing sections, the related computer programs have been developed. The flow chart of the overall simulation scheme is presented in Fig. 3, and details of the water balance computation are shown in Fig. 4.

Several simulation runs are made in order to arrive at suitable planting dates for the economic crops under consideration. Although these dates depend on many factors such as labour availability, farmers' habit,

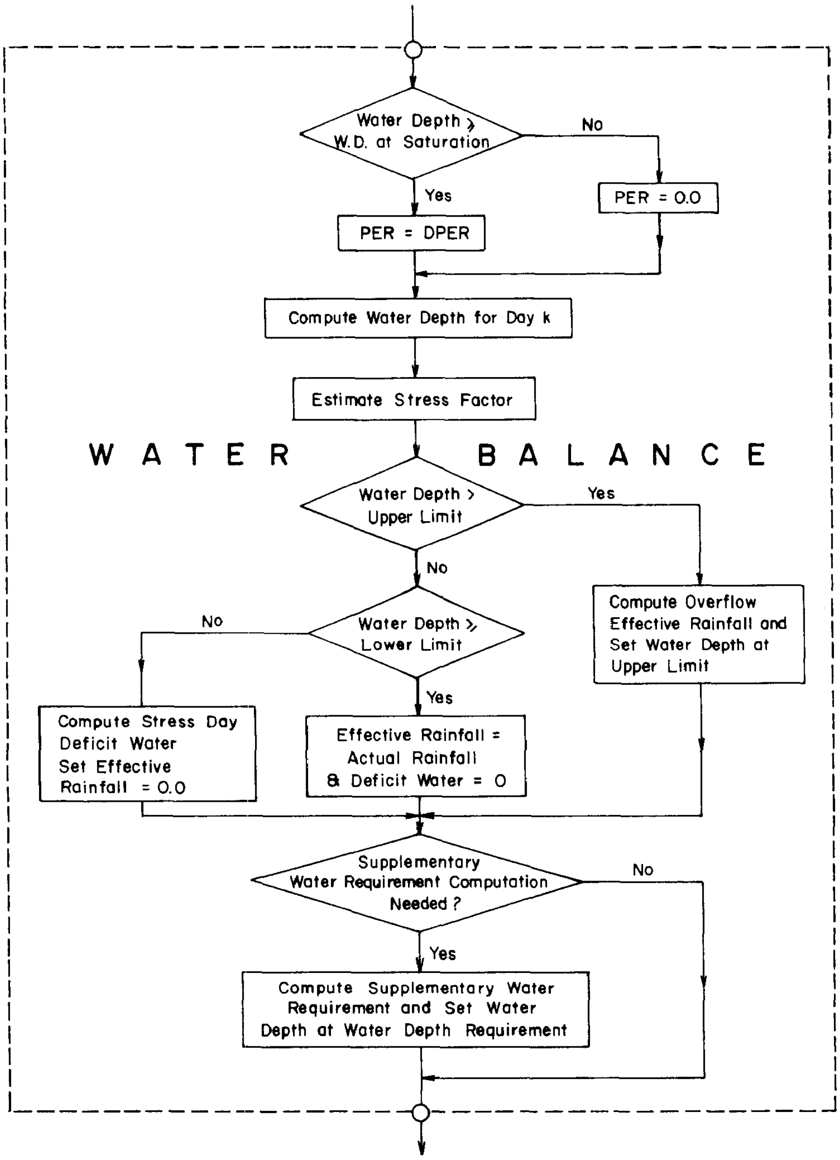

Fig. 4 Water Balance Computational Scheme

etc., only two of them were used as the decision factors in this work. These are stress days and drainage requirement.

For stress days, all the important descriptions (namely the total number, time of occurrence, frequency of occurrence for each duration and severity) were considered. The severity is considered most important in this study. It is represented by the stress coefficient Ks or by the stress day factor [Hiler and Clark 1971] defined as:

$$Sd = 1 - Ks \tag{37}$$

The amount of deficit water corresponding to each duration of stress days can also be evaluated by the following equation:

$$ADW = \underset{k=1,\ldots,Ns}{\text{Maximum}}\,[DW_k] \tag{38}$$

where

$$DW_k = DMIN - WD_k \quad (\text{when } WD_k < DMIN) \tag{39}$$

and Ns is the duration (in days) of the spell of stress days being considered. This may be treated as the minimum amount of supplementary water in order to avoid the corresponding stress spell. The minimum amount of supplementary water required in a month or during the entire growing season may be computed accordingly by summing up the individual amounts needed in the different spells, if any, covered by that month or the growing season.

From several simulation runs, a 30-year period was found to provide stable results (in the sense that a longer simulation period provides almost the same results).

## Typical Simulated Results

Almost all monthly rainfall sequences in different regions of Thailand may be fitted by the leakage law [Phien *et al.* 1980]. Moreover, during the wet season, monthly rainfall sequences may also be fitted by the lognormal and gamma distributions. Verification of this fitting has also been made for many more stations selected throughout the country. Typical results are collected in Tables 1 through 5 for five stations: Nan, Chaiyaphum, Nakhon Sawan, Surat Thani and Trang. This fitting was used as a basis for the first evaluation of rainfed agriculture potential in Thailand. Other statistical properties of monthly rainfall sequences in Thailand have been provided elsewhere [*ibid.*; Anukularmphai *et al.* 1980]. In this study, only typical simulated results are presented for evaluating the performance of the Rainfall Model and showing the capability of the

**Table 1** The Kolmogorov-Smirnov Statistic Computed in Fitting Monthly Rainfall at NAN (Long.: 100°86′E, Lat.: 18°46′N, Record: 1952–1978)

| Month | Distributions | | |
|---|---|---|---|
| | Leakage | Log-normal | Gamma |
| Jan. | 0.127 | — | — |
| Feb. | 0.077 | — | — |
| Mar. | 0.088 | — | — |
| Apr. | 0.120 | 0.163 | 0.138 |
| May | 0.100 | 0.111 | 0.092 |
| Jun. | 0.113 | 0.150 | 0.127 |
| Jul. | 0.135 | 0.179 | 0.145 |
| Aug. | 0.089 | 0.118 | 0.097 |
| Sept. | 0.121 | 0.161 | 0.136 |
| Oct. | 0.086 | 0.136 | 0.094 |
| Nov. | 0.174 | — | — |
| Dec. | 0.092 | — | — |

— not applicable because of existing zero values

**Table 2** The Kolmogorov-Smirnov Statistic Computed in Fitting Monthly Rainfall at CHAIYAPHUM (Long.: 102°02′E, Lat.: 15°48′N, Record: 1952–1978)

| Month | Distributions | | |
|---|---|---|---|
| | Leakage | Log-normal | Gamma |
| Jan. | 0.075 | — | — |
| Feb. | 0.050 | — | — |
| Mar. | 0.139 | — | — |
| Apr. | 0.084 | 0.062 | 0.070 |
| May | 0.112 | 0.141 | 0.130 |
| Jun. | 0.125 | 0.153 | 0.134 |
| Jul. | 0.101 | 0.070 | 0.095 |
| Aug. | 0.162 | 0.090 | 0.065 |
| Sept. | 0.128 | 0.086 | 0.113 |
| Oct. | 0.093 | 0.202 | 0.178 |
| Nov. | 0.113 | — | — |
| Dec. | 0.067 | — | — |

— not applicable because of existing zero values

**Table 3** The Kolmogorov-Smirnov Statistic Computed in Fitting Monthly Rainfall at NAKHON SAWAN (Long.: 100°10′E, Lat.: 15°48′N, Record: 1952–1978)

| Month | Distributions | | |
|---|---|---|---|
| | Leakage | Log-normal | Gamma |
| Jan. | 0.160 | — | — |
| Feb. | 0.176 | — | — |
| Mar. | 0.083 | — | — |
| Apr. | 0.090 | 0.105 | 0.119 |
| May | 0.061 | 0.059 | 0.058 |
| Jun. | 0.071 | 0.116 | 0.088 |
| Jul. | 0.110 | 0.145 | 0.121 |
| Aug. | 0.099 | 0.086 | 0.096 |
| Sept. | 0.098 | 0.131 | 0.109 |
| Oct. | 0.073 | 0.145 | 0.094 |
| Nov. | 0.222 | — | — |
| Dec. | 0.040 | — | — |

— not applicable because of existing zero values

Water Balance Model.

**Table 4** The Kolmogorov-Smirnov Statistic Computed in Fitting Monthly Rainfall at SURAT THANI (Long.: 99°21′E, Lat.: 09°07′N, Record: 1952–1978)

| Month | Distributions | | |
|---|---|---|---|
| | Leakage | Log-normal | Gamma |
| Jan. | 0.131 | 0.117 | 0.884* |
| Feb. | 0.082 | — | — |
| Mar. | 0.094 | — | — |
| Apr. | 0.143 | 0.174 | 0.940* |
| May | 0.096 | 0.099 | 0.102 |
| Jun. | 0.075 | 0.107 | 0.082 |
| Jul. | 0.074 | 0.091 | 0.071 |
| Aug. | 0.106 | 0.132 | 0.117 |
| Sept. | 0.099 | 0.130 | 0.110 |
| Oct. | 0.143 | 0.135 | 0.129 |
| Nov. | 0.100 | 0.134 | 0.116 |
| Dec. | 0.115 | 0.170 | 0.136 |

— not applicable because of existing zero values

* not fitted at the 5% significance level

**Table 5** The Kolmogorov-Smirnov Statistic Computed in Fitting Monthly Rainfall at TRANG (Long.: 99°38′E, Lat.: 07°31′N, Record: 1952–1978)

| Month | Distributions | | |
|---|---|---|---|
| | Leakage | Log-normal | Gamma |
| Jan. | 0.157 | — | — |
| Feb. | 0.096 | — | — |
| Mar. | 0.107 | — | — |
| Apr. | 0.066 | 0.137 | 0.082 |
| May | 0.091 | 0.125 | 0.102 |
| Jun. | 0.103 | 0.129 | 0.106 |
| Jul. | 0.077 | 0.097 | 0.075 |
| Aug. | 0.062 | 0.094 | 0.075 |
| Sept. | 0.072 | 0.080 | 0.064 |
| Oct. | 0.127 | 0.158 | 0.137 |
| Nov. | 0.070 | 0.108 | 0.082 |
| Dec. | 0.094 | 0.181 | 0.115 |

— not applicable because of existing zero values

### *(1) Performance of the Rainfall Model*

Evaluation of the model for daily rainfall generation was made in AIT [1981; 1983], using the reproduction of the following statistics as criteria: distribution of monthly rainfall, maximum amounts of daily rainfall,

**Table 6** Reproduction of Monthly Rainfall Distribution Accessed by the Mann-Whitney Test*

| Station | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. | Overall |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nan | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 100% |
| Chaiyaphum | 10 | 10 | 10 | 9 | 10 | 10 | 9 | 10 | 9 | 10 | 10 | 10 | 97.5% |
| Nakhon Sawan | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 9 | 99.2% |
| Surat Thani | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 100% |
| Trang | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 100% |

* for 10 generated sequences, each having the same length as the historical record

and frequencies of wet and dry spells. Because of its importance in this simulation study, typical results are also provided for the aforementioned five additional stations.

*Reproduction of Monthly Rainfall Distribution* Instead of using the Kolmogorov-Smirnov test for each of the distribution: leakage law, gamma and lognormal, the Mann-Whitney test [Gibbons 1971] was used in order to simply check if the generated and historical sequences have the same distribution (without particular reference to any of the above distributions). From Table 6, the percentage of times that the generated monthly sequence has the same distribution as the historical record is very high (97.5%), indicating that monthly rainfall distribution is reproduced by the presented model.

*Reproduction of Maximum Amounts of Daily Rainfall* In order to save space, the largest, average and smallest values of the relative errors for the mean and standard deviation of the maximum amount of rainfall for all the months of the year are collected. The relative error (in percentage) for the mean is defined as:

$$e=100(\bar{R}-\bar{R}')/\bar{R} \tag{40}$$

where $\bar{R}$ and $\bar{R}'$ are the means of maximum amount of daily rainfall (in a month) computed from the historical record and 10 generated sequences, respectively. In a year (12 months), 12 relative errors for the mean are obtained. The largest, average, and smallest values of these 12 errors are then computed and tabulated. The same definition and computation apply to the standard deviation. They are both shown in Table 7.

**Table 7** Relative Errors (in Percentage) in Reproducing the Mean and Standard Deviation of Maximum Amounts of Daily Rainfall

| Station | Mean | | | Standard Deviation | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (1) | (2) | (3) |
| Nan | 23 | −4 | 0 | 37 | −10 | 4 |
| Chaiyaphum | 24 | 9 | 0 | 39 | −7 | 0.9 |
| Nakhon Sawan | 26 | 0 | 0 | 44 | 9 | 4 |
| Surat Thani | 10 | −1 | 0.2 | 35 | 1 | 4 |
| Trang | 22 | −4 | 1 | 43 | −10 | 0 |

(1) Largest (in absolute value) error
(2) Average error
(3) Smallest (in absolute value) error

The largest relative error may appear to be high but with only 10 generated sequences, even larger discrepancy is commonly experienced in simulation studies. Moreover, the average relative error is quite small indicating a good reproduction of the mean and standard deviation of maximum amounts of daily rainfall.

*Reproduction of Frequencies of Dry and Wet Spells* Although the dry and wet spells at different duration were defined according

**Table 8** Average Relative Errors (in Percentage) in Reproducing Frequencies of Dry and Wet Spells

| Station | Dry Spells | Wet Spells |
|---|---|---|
| Nan | 9 | 0.7 |
| Chaiyaphum | 2 | 7 |
| Nakhon Sawan | 10 | 1 |
| Surat Thani | −3 | −2 |
| Trang | −2 | −0.4 |

to the theory of runs [AIT 1981], and their frequencies of occurrence were computed accordingly for all the 12 months of the year, only the average relative error for all the durations (from one day to m = the number of days in the month under consideration) is presented. Computed values are shown in Table 8 for both dry and wet spells. From the table it is clear that the frequencies of dry and wet spells of the historical record are well reproduced.

### *(2) Capability of the Water Balance Model*

The revised Water Balance Model was used in many simulation trials in order to determine suitable planting dates and related information for eight economic crops being cultivated in Thailand. These crops are paddy, corn, peanuts, sorghum, soybean, mungbean, cotton and kenaf; and the information contains stress conditions, drainage requirement, effective rainfall, and supplementary water requirement. In this section, some typical simulated results at Nakhon Sawan are presented for illustrations and discussions.

(a) Paddy. For paddy, two soil types namely clay and clay loam were considered because they are most suitable for paddy. As indicated by AIT [1983], August 1 is a suitable planting date for paddy on both soil types. The simulated results are shown in Table 9. Since there is no stress day in all the months of the growing season, the most severe condition is expressed by (0; 0; 0) where generally, (a; b; c) indicates that the most severe case occurs with a stress day factor (Sd) = a, a duration = b days, and a frequency = c% (meaning c times in 100 years). Although the drainage requirement is relatively large, the amount of effective rainfall is large also indicating that rain water is effectively

**Table 9** Simulated Results for Paddy Planted August 1 in Nakhon Sawan

| Month | | Stress Condition (1) | (2) | Drainage Requirement (mm) | Effective Rainfall (mm) |
|---|---|---|---|---|---|
| August | (H) | 0.0 | (0; 0; 0) | 37.4 | 179.9 |
| | (M) | 0.0 | (0; 0; 0) | 59.2 | 183.8 |
| September | (H) | 0.0 | (0; 0; 0) | 46.8 | 205.5 |
| | (M) | 0.0 | (0; 0; 0) | 58.1 | 218.6 |
| October | (H) | 0.0 | (0; 0; 0) | 196.4 | 106.8 |
| | (M) | 0.0 | (0; 0; 0) | 272.3 | 112.6 |
| November* | (H) | 0.0 | (0; 0; 0) | 0.4 | 6.6 |
| | (M) | 0.0 | (0; 0; 0) | 0.4 | 6.6 |
| Overall | (H) | 0.0 | (0; 0; 0) | 281.1 | 498.8 |
| | (M) | 0.0 | (0; 0; 0) | 383.7 | 521.7 |

* Growing season extends only eight days into November

(1) Total number of stress days (days)

(2) Most severe stress conditions: (0; 0; 0) means that the maximum stress day factor is 0, the duration of stress is 0, and the corresponding frequency is 0.

(H): clay; (M): clay loam

used. So, August 1 is clearly a suitable planting date for paddy in Nakhon Sawan.

**Table 10** Simulated Results for Corn Planted September 1 in Nakhon Sawan on Clay

| Month | Stress Condition | | Minimum Supplementary Water | Drainage Requirement | Effective Rainfall |
|---|---|---|---|---|---|
| | (1) | (2) | (mm) | (mm) | (mm) |
| September | 4.6 | (0.14; 3; 17) | 9.9 | 49.6 | 183.1 |
| October | 3.0 | (0.03; 10; 7) | 8.3 | 0.3 | 106.1 |
| November* | 3.4 | (0.05; 10; 10) | 10.0 | 0.0 | 17.1 |
| Overall | 11.0 | (0.14; 3; 17) | 28.1 | 49.9 | 306.3 |

* Growing season extends only 19 days into November
(1) Total number of stress days
(2) Most severe stress conditions (Maximum value of Sd; duration in days; frequency in %)

**Table 11** Simulated Results for Corn Planted August 25 on Clay Loam (M) and Sandy Loam (L) in Nakhon Sawan

| Month | | Stress Condition | | Minimum Supplementary Water | Drainage Requirement | Effective Rainfall |
|---|---|---|---|---|---|---|
| | | (1) | (2) | (mm) | (mm) | (mm) |
| August* | (M) | 0.4 | (0.08; 1; 13) | 5.7 | 15.2 | 22.3 |
| | (L) | 0.9 | (0.16; 1; 27) | 6.3 | 14.0 | 21.4 |
| September | (M) | 0.0 | (0; 0; 0) | 0.0 | 30.4 | 167.3 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 4.2 | 212.9 |
| October | (M) | 0.0 | (0; 0; 0) | 0.0 | 0.4 | 133.1 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 135.8 |
| November* | (M) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 9.6 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 9.6 |
| Overall | (M) | 0.4 | (0.08; 1; 13) | 5.7 | 46.1 | 323.3 |
| | (L) | 0.9 | (0.16; 1; 27) | 6.3 | 14.9 | 383.4 |

* Growing season extends only seven days and 12 days into August and November, respectively
(1) Total number of stress days
(2) Most severe stress conditions (for example, maximum value of Sd=0.08; duration=one day; frequency of occurrence=13 times in 100 years)

(b) Corn. For clay, September 1 was found to be a suitable planting date for corn in Nakhon Sawan [*ibid.*]. From the simulated results collected in Table 10, the most severe stress spell would be expected to occur in September with the maximum value of stress day factor Sd=0.14, duration of spell=three days and frequency of occurrence=17%. For the entire growing season, the total number of stress days is 11 days. However, even in the most severe case, the value of Sd is quite small. Consequently, there should be no damage to the crop. In Table 10, the minimum supplementary water requirement is also provided. This is the amount of irrigation water to be supplied in order to avoid the occurrence of stress days. Of course, the actual supplementary water (computed as the quantity needed to bring the water depth back to the water depth requirement immediately following a stress day) can also be estimated.

For clay loam and

sandy loam, August 25 is a suitable planting date for corn in Nakhon Sawan [*ibid.*]. The simulated results collected in Table 11 clearly indicate that this is a good planting date: the number of stress days is small, and the stress condition is not severe at all. Moreover, while the drainage requirement is small, the effective rainfall is high indicating that available rain water is used effectively.

(c) Peanuts. June 25 was found to be a suitable planting date for peanuts on all soil types under consideration [*ibid.*]. The corresponding simulated results on clay (H), clay loam (M), and sandy loam (L) are shown in Table 12. The number of stress days for the entire growing season is higher than that given in AIT [*ibid.*] for all the soil types while the drainage requirement is smaller. In the present study, the most severe stress spell is found to have different duration for different soil type. On clay, the most severe spell lasts for seven days in July with a frequency of occurrence of 13 times in 100 years. On clay loam, it lasts six days and the frequency of occurrence is 17 times in 100 years. Finally, on sandy loam it lasts two days with a frequency of occurrence of 40 times in 100 years. However, for all these soil types, the corresponding value of the stress day factor is quite small, therefore, no damage to the crop would be caused by the stress conditions. In other words, June 25 is a suitable planting date for peanuts in Nakhon Sawan.

**Table 12** Simulated Results for Peanuts Planted June 25 in Nakhon Sawan

| Month | | Stress Condition (1) | (2) | Minimum Supplementary Water (mm) | Drainage Requirement (mm) | Effective Rainfall (mm) |
|---|---|---|---|---|---|---|
| June* | (H) | 0.5 | (0.05; 1; 20) | 2.5 | 5.2 | 17.5 |
| | (M) | 0.7 | (0.09; 2; 20) | 3.6 | 3.5 | 19.1 |
| | (L) | 1.1 | (0.17; 2; 20) | 9.2 | 1.3 | 19.3 |
| July | (H) | 11.9 | (1.11; 7; 13) | 17.3 | 12.4 | 92.7 |
| | (M) | 12.3 | (0.13; 6; 17) | 17.7 | 7.2 | 95.5 |
| | (L) | 11.3 | (0.20; 2; 40) | 17.1 | 3.3 | 107.4 |
| August | (H) | 1.2 | (0.05; 3; 7) | 4.4 | 59.4 | 106.6 |
| | (M) | 1.2 | (0.05; 3; 7) | 5.1 | 21.7 | 144.1 |
| | (L) | 0.9 | (0.04; 2; 13) | 3.8 | 0.0 | 166.7 |
| September | (H) | 0.0 | (0; 0; 0) | 0.0 | 128.2 | 128.1 |
| | (M) | 0.0 | (0; 0; 0) | 0.0 | 93.7 | 162.6 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 18.3 | 227.4 |
| October | (H) | 0.0 | (0; 0; 0) | 0.0 | 37.6 | 106.0 |
| | (M) | 0.0 | (0; 0; 0) | 0.0 | 23.1 | 120.5 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 139.9 |
| November* | (H) | 0.0 | (0; 0; 0) | 0.0 | 8.0 | 7.7 |
| | (M) | 0.0 | (0; 0; 0) | 0.0 | 5.8 | 9.9 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 15.7 |
| Overall | (H) | 13.6 | (0.11; 7; 13) | 24.2 | 250.8 | 458.7 |
| | (M) | 14.2 | (0.13; 6; 17) | 26.3 | 155.1 | 551.7 |
| | (L) | 13.3 | (0.20; 2; 40) | 30.1 | 22.9 | 678.2 |

* Growing season extends only six days and 11 days into June and November, respectively

(1) Total number of stress days

(2) Most severe stress conditions

(H): clay; (M): clay loam; (L): sandy loam

(d) Sorghum. As indicated in AIT [*ibid.*], August 1 is a suitable planting date for sorghum on all the soil types under consideration. With this planting date, the simulated results are collected in Table 13. These results clearly support the previously recommended date: the total number of stress

**Table 13** Simulated Results for Sorghum Planted August 1 in Nakhon Sawan

| Month | | Stress Condition | | Minimum Supplementary Water | Drainage Requirement | Effective Rainfall |
|---|---|---|---|---|---|---|
| | | (1) | (2) | (mm) | (mm) | (mm) |
| August | (H) | 6.5 | (0.13; 7; 13) | 186.1 | 42.7 | 127.5 |
| | (M) | 6.9 | (0.17; 3; 20) | 186.5 | 35.4 | 132.7 |
| | (L) | 7.2 | (0.19; 2; 40) | 201.4 | 27.5 | 146.7 |
| September | (H) | 0.3 | (0.06; 3; 7) | 32.2 | 85.3 | 174.7 |
| | (M) | 0.3 | (0.06; 3; 7) | 32.1 | 30.1 | 229.9 |
| | (L) | 0.5 | (0.02; 3; 7) | 36.4 | 0.0 | 260.6 |
| October | (H) | 0.3 | (0.01; 6; 3) | 23.4 | 17.0 | 118.2 |
| | (M) | 0.3 | (0.01; 4; 3) | 20.8 | 7.1 | 128.1 |
| | (L) | 0.4 | (0.02; 3; 3) | 21.2 | 0.0 | 135.2 |
| November | (H) | 1.0 | (0.02; 3; 3) | 51.8 | 0.0 | 24.8 |
| | (M) | 1.0 | (0.02; 30; 3) | 51.3 | 0.0 | 24.8 |
| | (L) | 1.0 | (0.01; 13; 3) | 50.5 | 0.0 | 24.8 |
| December* | (H) | 0.4 | (0.02; 13; 3) | 42.1 | 0.0 | 1.9 |
| | (M) | 0.4 | (0.02; 13; 3) | 41.9 | 0.0 | 1.9 |
| | (L) | 0.4 | (0.02; 13; 3) | 42.0 | 0.0 | 1.9 |
| Overall | (H) | 8.5 | (0.13; 7; 13) | 335.7 | 145.0 | 447.1 |
| | (M) | 8.9 | (0.17; 3; 20) | 332.6 | 72.6 | 517.2 |
| | (L) | 9.5 | (0.19; 2; 40) | 351.5 | 27.5 | 569.3 |

* Growing season extends only 13 days into December

(1), (2), (H), (M), (L) as in Table 12

**Table 14** Simulated Results for Soybean Planted August 20 in Nakhon Sawan

| Month | | Stress Condition | | Minimum Supplementary Water | Drainage Requirement | Effective Rainfall |
|---|---|---|---|---|---|---|
| | | (1) | (2) | (mm) | (mm) | (mm) |
| August* | (H) | 1.2 | (0.08; 3; 10) | 32.3 | 25.9 | 44.5 |
| | (M) | 1.5 | (0.10; 4; 10) | 49.3 | 17.6 | 47.1 |
| | (L) | 1.8 | (0.10; 5; 13) | 21.4 | 9.2 | 51.0 |
| September | (H) | 0.7 | (0.06; 7; 7) | 19.5 | 93.7 | 132.7 |
| | (M) | 0.7 | (0.03; 7; 3) | 49.1 | 20.0 | 170.3 |
| | (L) | 0.6 | (0.03; 7; 3) | 36.4 | 0.2 | 221.0 |
| October | (H) | 1.6 | (0.02; 25; 3) | 72.9 | 10.2 | 123.2 |
| | (M) | 0.7 | (0.01; 12; 3) | 43.5 | 1.8 | 131.6 |
| | (L) | 0.2 | (0; 0; 0) | 13.7 | 0.0 | 135.6 |
| November* | (H) | 0.5 | (0.08; 3; 10) | 11.0 | 0.0 | 9.6 |
| | (M) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 9.6 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 9.6 |
| Overall | (H) | 4.0 | (0.08; 3; 10) | 135.7 | 129.8 | 310.1 |
| | (M) | 2.9 | (0.10; 4; 10) | 141.9 | 48.3 | 358.7 |
| | (L) | 2.5 | (0.10; 5; 13) | 71.5 | 9.4 | 417.2 |

* Growing season extends only 12 days into August and November

(1), (2), (H), (M), (L) as in Table 12

days is small; the stress condition is not severe; the drainage requirement is small; and the available rain water is used effectively.

(e) Soybean. In this study, it was found that August 20 is a suitable planting date for all the soil types (not only for clay, as in AIT [*ibid.*]). The simulated results are collected in Table 14. Clearly August 20 is a suitable planting date for soybean in Nakhon Sawan.

(f) Cotton. For cotton, July 10 was found to be a suitable planting date for all the three soil types. The simulated results are collected in Table 15. The number of stress days is small; the stress condition is not severe; and available rain water is used effectively. In other words, July 10 is a good planting date for cotton in Nakhon Sawan.

It should be noted that for clay, the maximum value of Sd was 0.10 in the months of July and August. However, from inspection of the amount of deficit water in these spells it was found that the first stress spell is more severe.

### *(3) Discussions*

(a) As mentioned previously, severity was considered most important in the selection of suitable planting dates. With the definitions of the stress day factor (Sd) and the amount of deficit water (ADW), the most severe spell can be picked up easily. It is the spell corresponding to the largest values of both Sd and ADW. The most severe stress conditions collected in Tables 10–15 were selected according to this scheme.

**Table 15** Simulated Results for Cotton Planted July 10 in Nakhon Sawan

| Month | | Stress Condition (1) | Stress Condition (2) | Minimum Supplementary Water (mm) | Drainage Requirement (mm) | Effective Rainfall (mm) |
|---|---|---|---|---|---|---|
| July* | (H) | 5.0 | (0.10; 8; 10) | 124.9 | 22.5 | 74.1 |
| | (M) | 5.3 | (0.17; 3; 17) | 154.4 | 15.3 | 75.5 |
| | (L) | 5.3 | (0.11; 2; 20) | 86.5 | 8.7 | 80.2 |
| August | (H) | 1.3 | (0.10; 3; 13) | 23.8 | 38.6 | 141.8 |
| | (M) | 1.4 | (0.10; 2; 17) | 28.3 | 5.8 | 164.5 |
| | (L) | 0.8 | (0.10; 3; 10) | 15.0 | 0.0 | 181.3 |
| September | (H) | 0.0 | (0; 0; 0) | 0.0 | 83.3 | 150.2 |
| | (M) | 0.0 | (0; 0; 0) | 0.0 | 20.3 | 191.3 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 1.5 | 230.9 |
| October | (H) | 0.0 | (0; 0; 0) | 0.0 | 29.0 | 124.8 |
| | (M) | 0.0 | (0; 0; 0) | 0.0 | 15.8 | 119.7 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 153.8 |
| November | (H) | 0.0 | (0; 0; 0) | 0.0 | 0.2 | 40.0 |
| | (M) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 40.2 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 40.2 |
| December* | (H) | 0.0 | (0; 0; 0) | 0.0 | 0.2 | 0.6 |
| | (M) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 0.6 |
| | (L) | 0.0 | (0; 0; 0) | 0.0 | 0.0 | 0.6 |
| Overall | (H) | 6.3 | (0.10; 8; 10) | 158.7 | 173.6 | 531.4 |
| | (M) | 6.7 | (0.17; 3; 17) | 192.7 | 57.1 | 601.8 |
| | (L) | 6.1 | (0.18; 2; 20) | 101.5 | 10.2 | 687.1 |

* Growing season extends 22 days into July and six days into December.
(1), (2), (H), (M), (L) as in Table 12

(b) From the results collected in Tables 12 through 15, a clear pattern seems to exist among the drainage requirement and effective rainfall for upland crops grown on different soil types: the drainage decreases and the effective rainfall increases from clay (H) to clay loam (M) and sandy loam (L).

(c) More information on stress condition was made available by the scheme presented in this study. Stress days may occur frequently but as long as the corresponding stress day factor (Sd) and the amount of deficit water are small, one should expect no damage to the crop. (Since the time of stress days occurrence is important, it is also provided in the detailed output of the computer program for the simulation work for careful evaluations of alternative planting dates.)

(d) The minimum amount of supplementary water may be computed as the minimum amount needed to avoid the occurrence of stress days. During any stress spell, when an amount of water equivalent to ADW is available, the crop may consume it and thus avoid the spell.

(e) The supplementary irrigation water should correspond to the actual amount of water to be supplied. However, in practical situations, one does not know when a stress day occurs so that irrigation can be made immediately following it. It would be desirable to forecast daily rainfall amounts with lead time equal to several days so that the assumption could be practically applied. At present, no successful methods are available for such forecasting purposes.

## Summary and Conclusions

In this study, a general model was developed for the assessment of rainfed agriculture in Thailand. It consists of three submodels for the three main components, namely, rainfall, evapotranspiration and water balance computation. The rainfall submodel was shown to be able to reproduce all important statistics of the historical record, and hence it was used to generate daily rainfall needed in the water balance computation. The selection of formulas for estimating the potential evapotranspiration depends largely on the time frame employed and the data available. For Thailand, Penman's formula and evaporation method were found suitable, with the latter being more applicable due to its less requirement of recorded data. The water balance computation was roughly schematized, however, all the simulated results shown in this study and elsewhere [AIT 1984] seemed to be reasonable. As such, the developed comprehensive model is clearly useful in providing all important information related to rainfed agriculture practices. The model is quite general in its structure. Consequently, it is expected to be applicable to many other areas in Southeast Asia with some minor modifications.

## Acknowledgements

The authors wish to express their gratitude to the Committee for Coordination and Acceleration of Water Resources Development, the Secretariat of the Prime Minister, Kingdom of Thailand for sponsoring the research project which is reported partly in this paper. They also wish to thank the Asian Institute of Technology for use of its research facilities throughout the period of study.

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