Paper

Estimation of Effective Rainfall in Wet Season Paddy —Observational studies on water requirement of lowland rice in Thailand(II)—

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Summary The water balance model has been modified and used in this study for the estimation of effective rainfall for lowland paddy. The component of interception was included in the water balance model. The relationship of interception to rainfall at three growth stages was established with the help of field experiments and utilized in the simulation. Eight rainfall stations in Thailand, whose rainfall records for the past 30 years are available, were selected for analysis. Simulation was run with computed crop water requirement and various values of percolation rate, ponding depth and irrigation interval to study their effects on effective rainfall, irrigation requirements and types of irrigation practiced. It was found that 150 mm ponding depth and 5/6 days irrigation interval is most suitable and economical for lowland rice from the effective rainfall and efficient irrigation point of view. An attempt has also been made to reflect the effects of major variables on certain farming conditions. The two programs developed for simulation and rainfall analysis were in FORTRAN 77 and were run in IBM 3083 at the Regional Computer Center, Asian Institute of Technology, Bangkok.

I. Introduction

In irrigated rice culture rainfall contributes directly a major part of the crop's water requirements. This is because it can be grown in standing water, which stores rain water and reduces the amount of supplementary irrigation necessary. In Southeast Asian countries the prevailing irrigation system sometimes permits excessive use of irrigation water due to improper planning in an irrigation system which does not include the actual contribution of effective rainfall. In fact effective rainfall makes a potential contribution at the farm level toward the goal of irrigation saving. So it is an important parameter in the economic feasibility of an irrigation system on a day-to-day management level.

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Research on estimating effective rainfall has been done for upland fields, for example Anyoji(1987), but very little has been done for lowland rice in Southeast Asia.

The broad objective of this study is to develop a simulation model for estimating effective rainfall based on the water balance method and to gain both perspective and a comprehensive picture of effective rainfall and irrigation requirements in Thailand for wet season rice. In addition, we have tried to determine the effect of several factors on the rate of effective rainfall in lowland paddy.

II. Methodology and Theoretical Considerations

1. Data Collection

Daily rainfall data for eight stations covering all the regions of Thailand were collected from the Royal Irrigation Department (RID), Bangkok. The names and

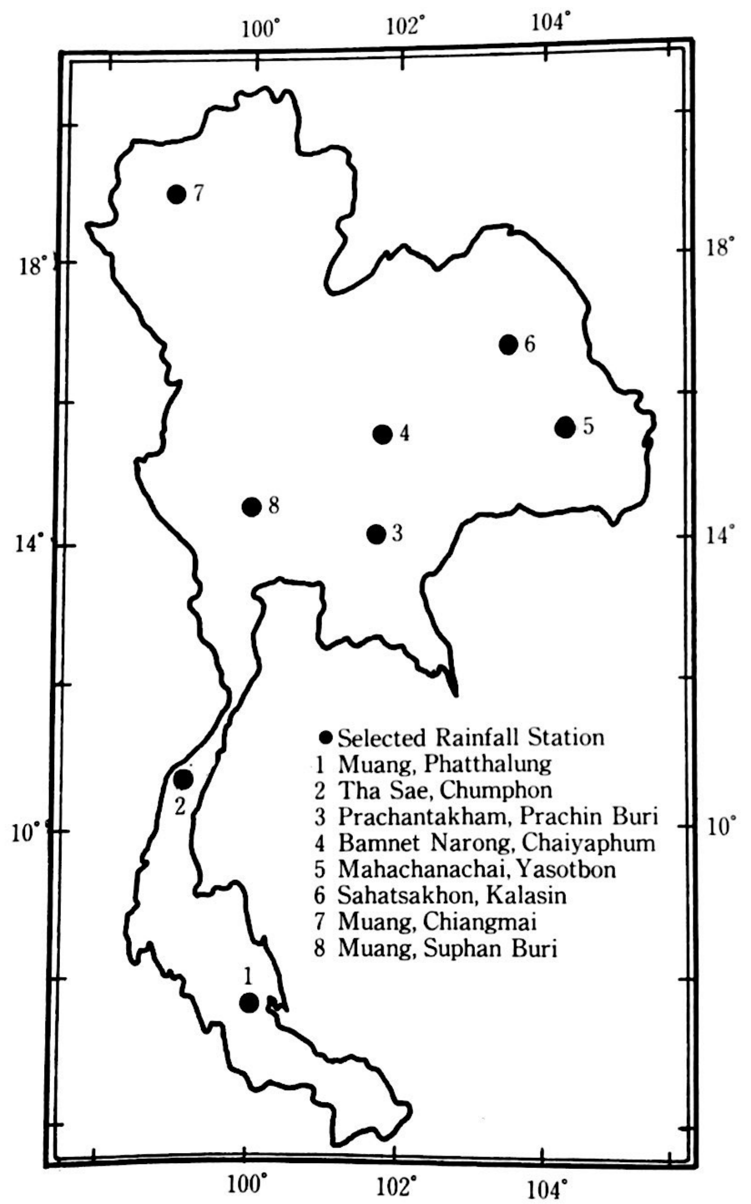

Figure 1 Location of selected rainfall stations

Table 1 Name, province and locations of selected rainfall stations

Station	Name	Region	Province	Location	
				Lat-N	Long-E
1	Muang	South	Phattalung	07° 37′ 02″	100° 04′ 32″
2	Tha Sae	South	Chumpon	10° 39′ 44″	99° 10′ 30″
3	Prachantakham	Central	Prachin Buri	14° 03′ 45″	101° 31′ 05″
4	Bamnet Narong	Northeast	Chaiyaphum	15° 29′ 56″	101° 41′ 24″
5	Maha Chanachai	Northeast	Yasothon	15° 31′ 50″	104° 14′ 50″
6	Sahatsakhon	Northeast	Kalasin	16° 42′ 40″	103° 31′ 34″
7	Muang	North	Chiang Mai	18° 50′ 23″	98° 58′ 32″
8	Muang	Central	Suphan Buri	14° 28′ 10″	100° 07′ 14″

locations of the stations are shown in **Figure 1** and **Table 1**. The data for a 30-year period (1955—1984), include the transplanting to ripening stage (1 July to 31 Oct.) which covers most of the growing period of wet season paddy in Thailand. Evaporation data from two stations of central Thailand, namely Bamnet Narong and Prachantakham, were collected from the Hydrological Division of RID, Bangkok, for 1984—1985. Data for actual crop coefficient of two high-yielding varieties, namely RD 7 and RD 11 for wet season rice from five different stations in Thailand, were provided by RID in a report written by Tongaram (1980). No data on seepage and percolation (vertical percolation and border percolation) were obtained. However, values estimated by Engineering Consultants Inc. (1972) for rice management group in Thailand were adopted. This value varies from 1 to 4 mm/d.

2. Experiment

To obtain evapotranspiration ratio (K_{c1}), actual evapotranspiration of rice crop, rainfall interception by plants (I_c), border percolation and vertical percolation (S & P) the experiments were carried out at the experiment field of the Asian Institute of Technology, Thailand, during the wet season of July to Oct., 1987. Three plots, namely plot 2, plot 3 and plot 4, which were illustrated in the previous paper (Mizutani et al., 1989), were utilized for the experiments. The variety Suphanburi 10, which is a cross between RD 7 and RD 1, non-photosensitive, and long-grained with a maturity of 120—130 days, was selected for the experimental study. As in the previous study, an N-type apparatus, a lysimeter, a cylinder box instrument, a sloping gauge and an automatic water level recorder were installed in each plot, and the readings were taken on a daily basis at 8:00 a.m. A raingauge and a U.S. Weather Bureau class A evaporation pan were installed at the side of the experimental plots in an open space, and readings were taken on a daily and weekly basis.

3. Evapotranspiration

ET ratio method is simple and suitable for estimation of evapotranspiration of rice crop (ET_c). Using this method, ET_c is calculated as

$$ET_c = K_c \times ET_o = K_p \times K_c \times E_{pan} = K_{c1} \times E_{pan} \quad (1)$$

where ET_o=reference crop evapotranspiration, E_{pan}=pan evaporation, K_c=crop coefficient, K_p=pan coefficient, and K_{c1}=evapotranspiration ratio.

4. Water Requirement

From the field experiment, the average ET ratio values of three experimental plots at different time stages at 10-day intervals were found to be between 0.72 and 1.31. The K_c values for pan evaporation method obtained from RID (Tongaram, 1980) when multiplied by K_p (0.75) also gave the ET ratio values. The overall average values of ET ratio from calculated and observed data are tabulated in **Table 2**. This shows that evapotranspiration is maximum between the 81st and 90th days after transplanting (DAT).

The average values of vertical percolation as observed from the experiment were 0.58 mm/d. The average value of the border percolation was found to be 7.62 mm/d, which is quite a bit higher than the recommended value (1—4 mm/d) due to the newly constructed levees. However, to account for the experimental results, in the simulation a higher value of 6 mm/d as S & P had been considered along with the other two values of 2 and 4 mm/d.

Table 2 Evapotranspiration, pan evaporation and ET ratio at different growth stages

Days after transplanting	Pan evaporation (mm)	ET ratio	ET_c (mm)
1— 10	3.99	0.84	3.35
11— 20	3.76	0.85	3.20
21— 30	4.16	0.82	3.41
31— 40	3.96	0.88	3.48
41— 50	3.56	1.03	3.66
51— 60	4.00	1.03	4.12
61— 70	3.62	1.18	4.28
71— 80	3.57	1.21	4.32
81— 90	3.96	1.21	4.79
91—100	3.89	1.23	4.78
101—110	3.34	1.37	4.57
111—120	3.84	1.18	4.53

5. Interception

The main components of rain water on its way to the paddy field, as mentioned by Daniane (1974), can be shown in **Figure 2.** Thus,

$$\begin{aligned} R &= C + B \\ &= C + B_1 + B_2 \end{aligned} \quad (2)$$

where R=precipitation, C=the part of rainfall that strikes the water surface, B=the part of rainfall that is intercepted by plants, B_1=the part of intercepted rainfall that is retained by plants and evaporates, and B_2=the part of intercepted rainfall that is drained on soil and water surface.

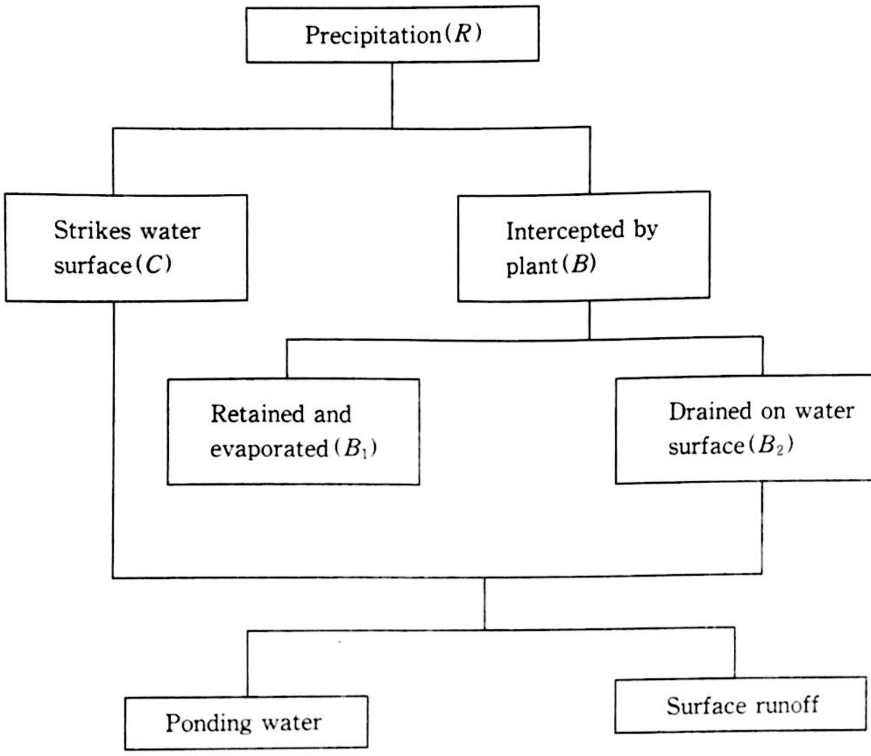

Figure 2 Pathway of rainfall to paddy field

In Eq. (2), B_1 is considered to be interception by plants (I_c) in this study. Precipitation was obtained from raingauge measurement. The actual rise of water level in lysimeter during rainfall (X) can be expressed as

$$X = C + B_2 - ET_a$$

where ET_a=actual evapotranspiration. Thus,

$$I_c = B_1 = R - X - ET_a \tag{3}$$

ET_a was assumed to be equal to the evapotranspiration of the next non-rainfall day. Due to the short duration of rainfall in the wet season, lasting less than 1 h as so called showers, climatic conditions such as temperature, humidity, wind velocity and so on are presumed to not very different on days with and without rainfall.

6. Simulation

Effective rainfall was determined by daily water balance caluculations under intermittently irrigated conditions. In the case of intermittent irrigation, the amount of irrigation required on the scheduled day is based on the additional water required to meet the crop water requirement for that day as well as the water requirement of the following non-irrigation days, when the available water depth for irrigation is excluded. Thus the total water requirement during the interval period is

$$IWR_i = \sum_{i}^{i+n} WR_i = \sum_{i}^{i+n} ET_{c_i} + (n+1)(S+P) \tag{4}$$

where i=day index, n=irrigation interval, S=loss per day due to border percolation or seepage, P=loss per day due to vertical percolation or percolation, IWR=interval water requirement, and WR=daily water requirement.

A simple water balance model for lowland paddy field is shown in **Figure 3**. The daily balancing of water level can be done based on the irrigation requirement calculated from the total water requirement for the interval period as in Eq. (4). Then available water depth of the next day can be calculated as

$$AWL_{i+1}=AWL_i+IRG_i+R_i-WR_i-SR_i-I_{c_i} \tag{5}$$

where AWL_i=available water depth at the beginning of i-th day, IRG_i=irrigation depth applied on the day, R_i=rainfall on the day, SR_i=surface runoff on the day, and I_{c_i}=interception by the plant on the day.

If the irrigation interval is n days, irrigation water depth on every $(n+1)$th day can be expressed as follows:

$$IRG_i=0, \quad \text{if } AWL_{i-1} \geqq IWR_i \tag{6}$$

$$IRG_i=IWR_i-AWL_i, \quad \text{if } AWL_{i-1}<IWR_i \tag{7}$$

Under the condition of Eq. (6), it is not necessary to practice irrigation as there is sufficient available water depth. Storage depth available for rainfall is

$$ST_i=MWL-AWL_i-IRG_i \tag{8}$$

$$SR_i=R_i-I_{c_i}-ST_i \tag{9}$$

where ST_i=storage depth available for rainfall on the day, and MWL=maximum allowable ponding depth.

Taking the safer side of operation and maintenance into consideration, effective rainfall on the day should depend on the surface runoff on the day due to insufficient storage.

$$\text{When } SR_i>0 \text{ i.e., } \quad ST_i<R_i-I_{c_i}, \quad RE_i=R_i-I_{c_i}-SR_i=ST_i \tag{10}$$

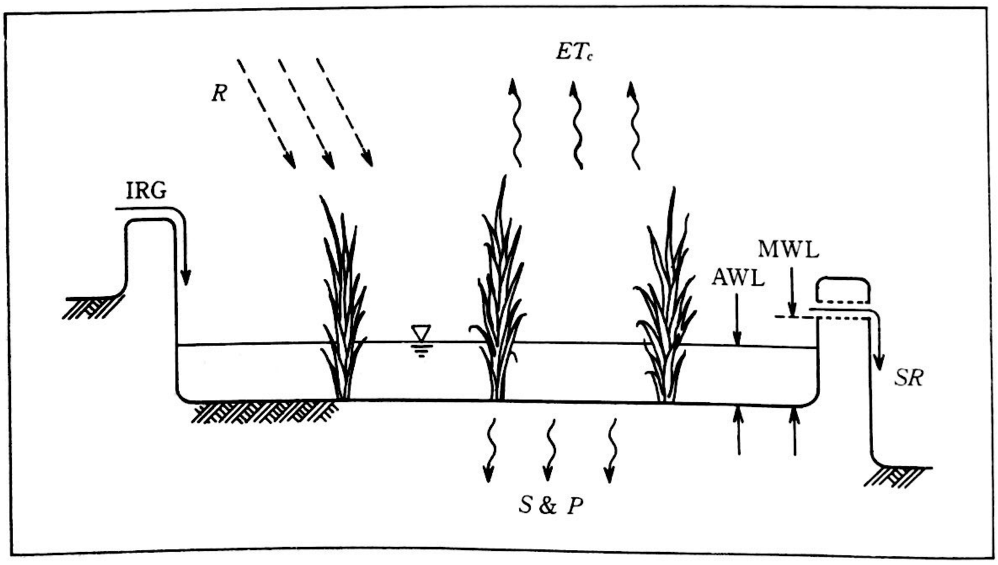

Figure 3 Water balance model for lowland rice

$$\text{When } SR_i=0 \text{ i.e., } ST_i \geqq R_i - I_{c_i},\quad RE_i = R_i - I_{c_i} - SR_i = R_i - I_{c_i} \tag{11}$$

where RE_i=effective rainfall on the i-th day.

Thus rainfall effectivity ratio for the entire season (RER) can be obtained as

$$RER=(\sum RE_i/\sum R_i)\times 100.$$

When irrigation interval is taken as one, i.e. $IWR_i=WR_i$, irrigation is practiced every day within a few hours until the amount of WR is supplied. This case is also recoginized as intermittent irrigation, because irrigation is not done all day long or continuously.

A computer program in FORTRAN 77 consisting of a main program and a subroutine was developed for the simulation process.

7. Variables and Assumptions

In this simulation program the different variables to find the effective rainfall from 30 years of rainfall recorded at 8 stations in Thailand are as given below:

1) Maximum allowable ponding depth (200, 180, 150, 120, 100 and 80 mm)
2) Irrigation interval (1, 2, 3, 4, 5, 6, 7 and 8 d)
3) Seepage and percolation (2, 4 and 6 mm/d)
4) ET_c (**Table 2**)

The main assumptions made in this simulation are as follows:

1) Irrigation is done not all day long but at certain hours until IWR is supplied on the schedule day.
2) S & P is uniform over the entire growth periods.
3) Initially soil is saturated and no water depth is available in the field, i.e., $AWL_1=0$.
4) Constant irrigation interval is maintained throughout the growing seasons, and fields are irrigated in sequence under intermittent irrigation.
5) Surface runoff is completed in the same day as a rainfall.
6) Effective rainfall and net irrigation requirements are taken as the average of all the fields under intermittent irrigation.

III. Results and Discussion

1. Rainfall Characteristics

After several trials it was observed that Gumbel Distribution is the suitable statistical descriptor of the growing-season rainfall in Thailand. On the basis of this, the probability of non-exceedance of rainfall during the rice growing season was determined, and the summarized results for all stations at a retrun periods of 2 years and 5 years are given in **Table 3**. This results clearly depicts the wide variation of rainfall in the country. From the analysis it is observed that south Thailand gets high average rainfall, 1640 mm at the station 1, whereas northeast Thailand gets very low rainfall, 611 mm at the station 4 on average. Based on the ET_c values in **Table 2** and S & P of 4 mm/d, the water requirement without effective rainfall in the wet season can be computed as 965 mm. Taking fluctua-

Table 3 Summarized results of probability analysis between 1 July and 31 October over 30 years (1955—1984)

Station	Rainfall (mm)				
	Minimum	Maximum	Average	Return period of	
				5 Years	2 Years
1	647	4012	1640	968	1341
2	375	1797	913	712	878
3	422	1539	1080	819	1055
4	270	1204	611	451	559
5	580	1331	905	712	879
6	172	1483	826	648	803
7	530	1007	757	635	747
8	430	1185	787	565	721
Overall average			940	689	872

tion in amounts of daily rainfall into account, all of the stations suffer water shortages at the return period of 5 years.

2. Interception

Interception was calculated by the methods mentioned in the previous section. During the first 10 days after transplanting, the amount of interception was almost negligible. As rainfall was not sufficient, the relationship between rainfall and interception is established only from three growth stages (11—41, 42—71

Table 4 Observed values of interception from rainfall at different growth stages

August		September		October	
Rainfall (mm)	Interception (mm)	Rainfall (mm)	Interception (mm)	Rainfall (mm)	Interception (mm)
1.00	1.00	0.50	0.50	0.60	0.60
1.80	1.30	0.80	0.80	1.20	1.20
1.90	1.35	1.00	1.00	4.50	1.75
2.00	1.40	1.40	1.00	15.20	1.95
3.85	1.40	1.70	1.20	20.00	2.00
9.60	1.70	1.80	1.30	22.30	2.00
11.40	1.70	2.00	1.40	24.50	2.30
17.00	1.75	2.10	1.50	48.10	2.15
		2.30	1.10		
		3.00	1.50		
		4.00	1.50		
		6.00	1.50		
		7.00	1.75		
		11.00	2.10		
		21.00	1.60		
		22.40	2.00		
		23.00	2.25		
		31.60	2.10		
		43.00	2.00		
		54.00	2.35		

and 72—102 DAT). The observed values of interception at three growth stages are given in **Table 4**. It is observed that interception tends to increase with rainfall and follows a logarithmic relationship as follows:

During August i.e., 11—41 DAT : $I_c = 1.04 + 0.244\ Ln(R)$; $r^2 = 0.91$ (12)

During September i.e., 42—71 DAT : $I_c = 1.00 + 0.327\ Ln(R)$; $r^2 = 0.87$ (13)

During October i. e., 72—102 DAT : $I_c = 1.02 + 0.344\ Ln(R)$; $r^2 = 0.90$ (14)

when $R \leqq 1.2$ mm, $I_c = R$ after 11 DAT
where r^2=correlation coefficient.

Eqs. (12), (13) and (14) are taken into account in the simulation of effective rainfall as an independent valuable of Eq. (5).

3. Relation between Effective Rainfall and Total Rainfall

The nomogram (**Figure 4**) shows the relationship of effective rainfall to total

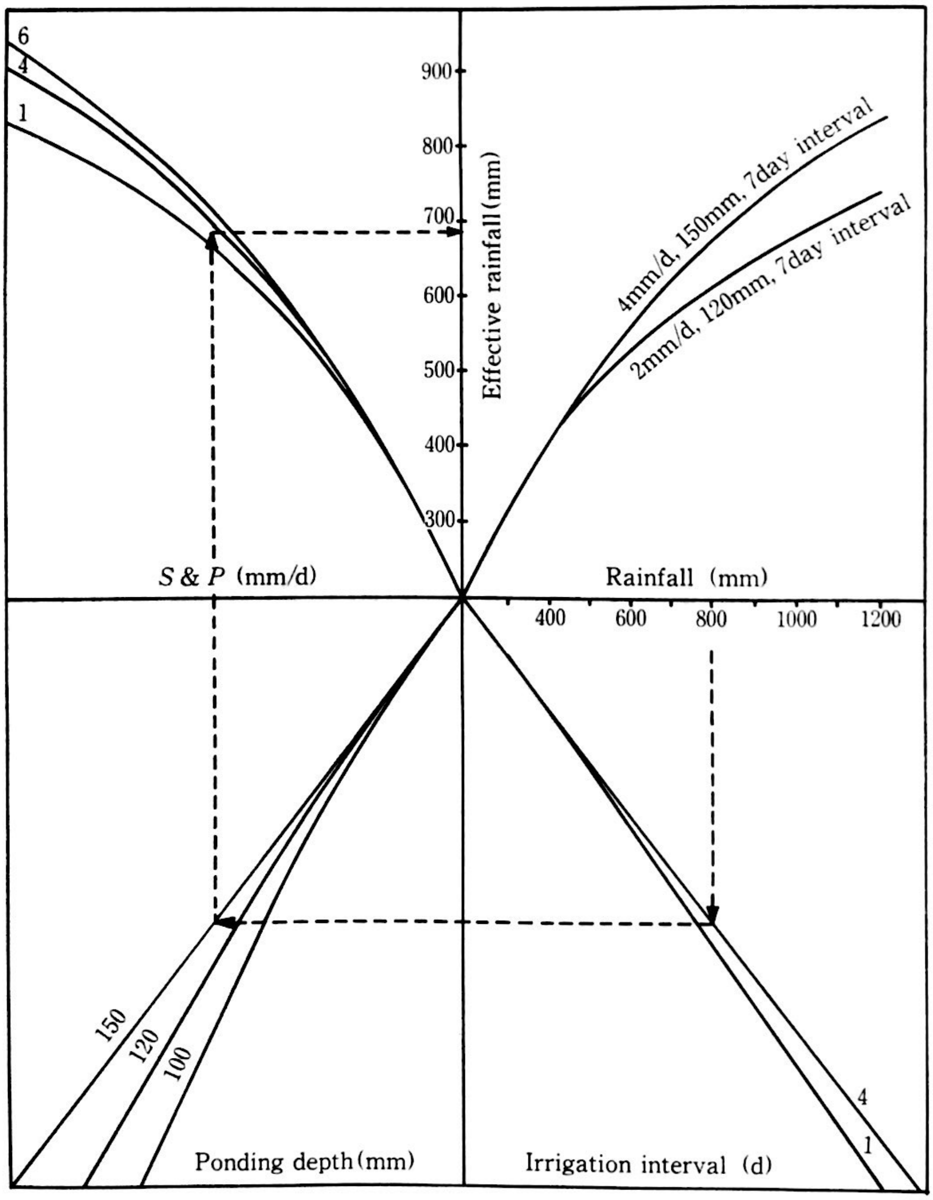

Figure 4 Nomogram for estimating effective rainfall and showing composite effect of different factors (station 4, at a return period of 5 years)

rainfall for station 4, which follows a logarithmic trend. The results for all the stations reveal that rainfall less than about 600 mm contributes almost equal amounts of effective rainfall (95 to 100%). Above this value the amount of effective rainfall increases with actual rainfall, but in a decreasing rate. At stations like 3 and 6, at very high intensity of rainfall, the rate of effective rainfall shows decreasing trend even if rainfall amount increases. This is because of the occurrence of very heavy rainfall over a few days. The monogram prepared for the estimate of effective rainfall from various factors is established from the separate relationships obtained at different irrigation intervals, ponding depths and percolation rates. This includes an error of 10—30% (r^2=0.70 to 0.90).

4. Relation between Effective Rainfall and Irrigation Requirement

There is a trade-off relation between effective rainfall and irrigation require-

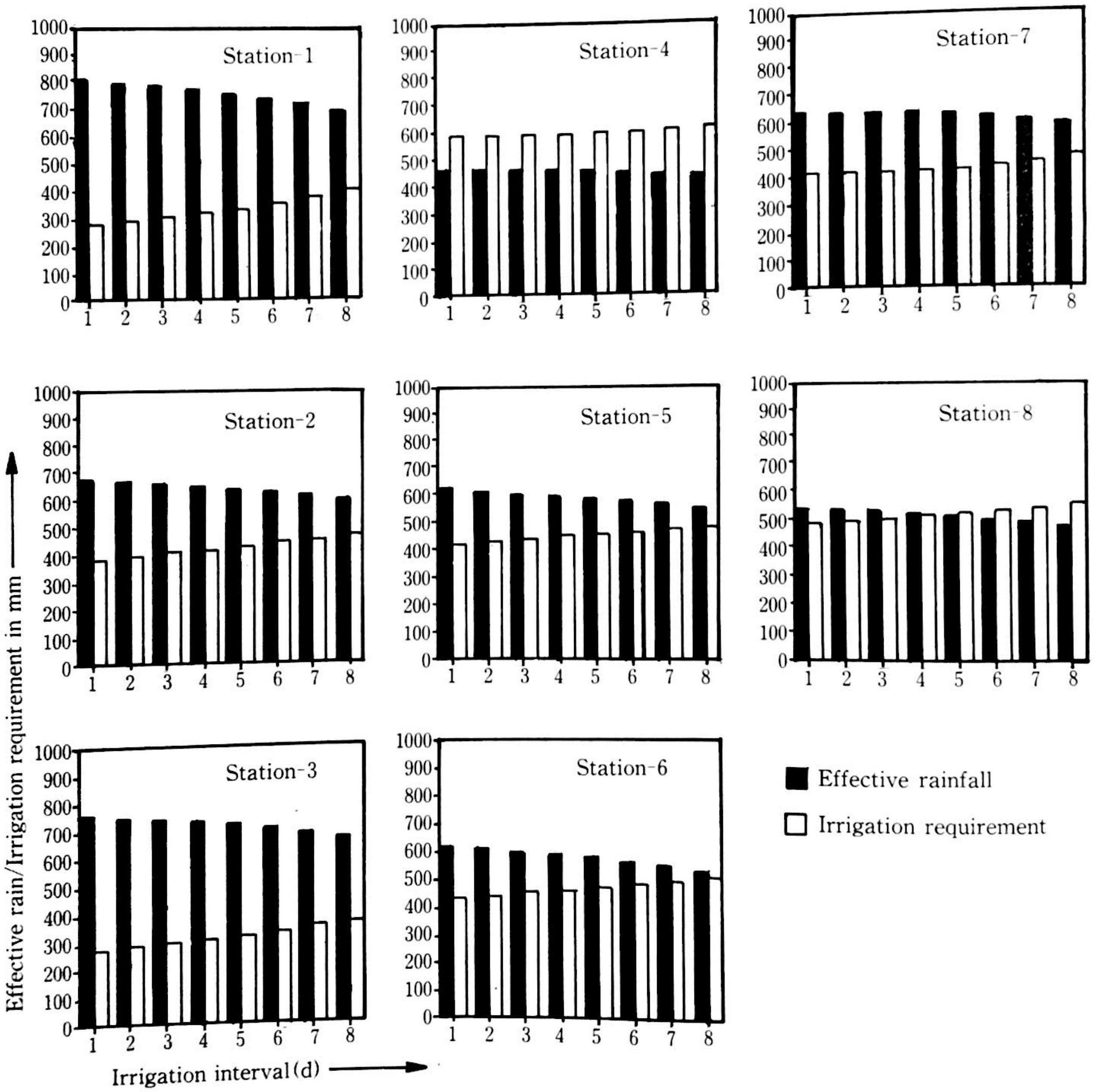

Figure 5 Effect of irrigation interval on effective rainfall and irrigation requirement (at a return period of 5 years, 4 mm/d percolation rate and 100 mm ponding depth)

ments, as shown in **Figure 5**. It is also seen that the amount of irrigation requirement increases with increase in irrigation interval, because a longer irrigation interval results in less available water depth for rainfall when the maximum allowable ponding depth is fixed in the same condition. In the case of one-day irrigation interval and at a return period of 5 years, it is observed that irrigation is indispensable at all of the stations in Thailand. Even at those stations where rainfall during wet season abounds, like stations 1 and 3, irrigation is needed for favorable growth of rice, although the amount of effective rainfall is more than twice the irrigation requirement. At station 4 irrigation is most urgently required due to insufficiency of rainfall.

5. Effect of Ponding Depth

It is obvious that with an increase in allowable ponding depth (MWL), effective rainfall amount increases due to the additional storage. **Figure 6** shows the simultaneous effect of ponding depth and percolation rate (seepage and percolation) on effective rainfall at a return period of 5 years for station 5. It is observed that when the ponding depth increases from 80 to 150 mm, the rate of increase is very high, but after 150 mm the rate of increase is lower. As the ponding depth suitable for paddy is less than 150 mm, and as at higher percolation rates the increase in saving of rainfall above this range is not great, it is better to go up to maximun 150 mm ponding depth.

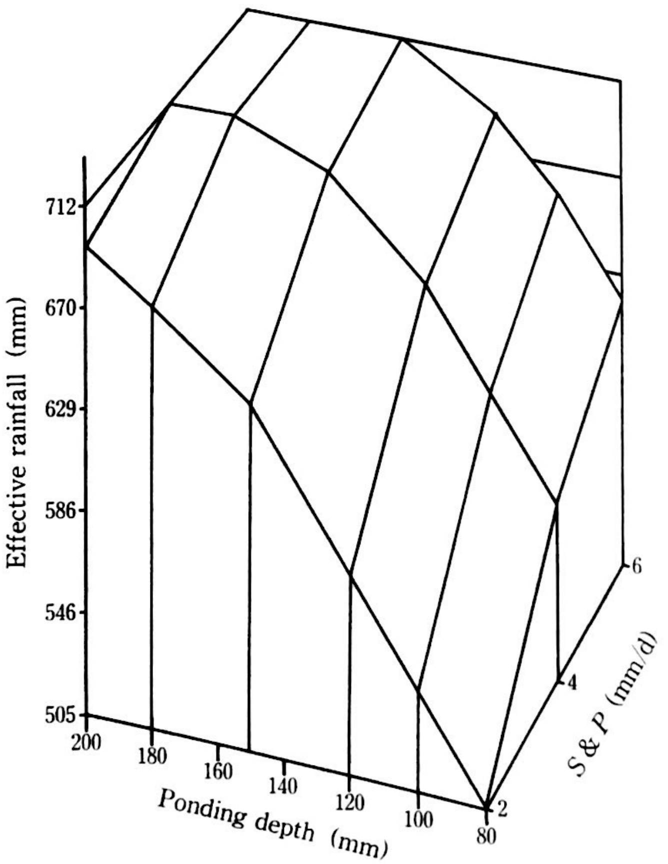

Figure 6 Effect of ponding depth and percolation rate on effective rainfall (station 5, at a return period of 5 years)

6. Effect of Percolation Rate

Percolation rate has a strong impact on effective rainfall. A higher rate results in lower water depth in the field and greater capacity to store rainfall, as shown in **Figure 6**. But high rate of percolation also increases the water requirement and in turn increases the net amount of irrigation. This is seen from **Figure 7**.

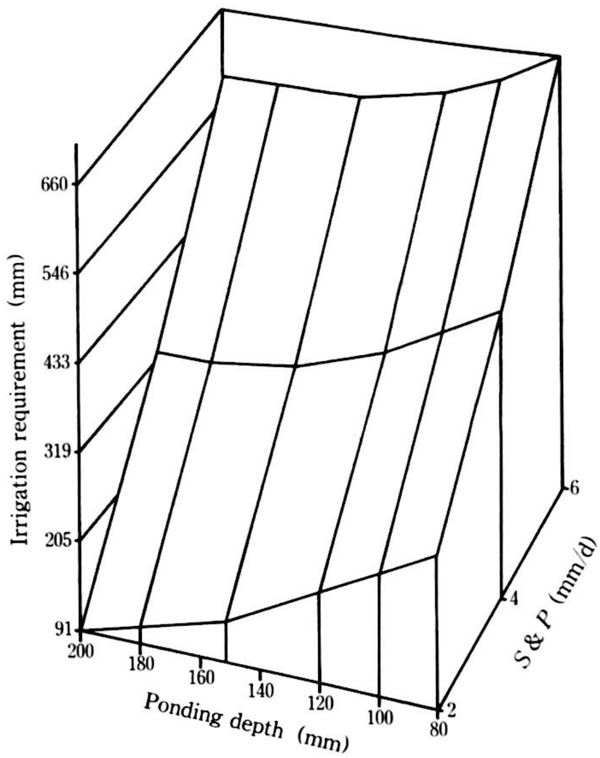

Figure 7 Effect of ponding depth and percolation rate on irrigation requirement (station 5, at a return period of 5 years)

7. Effect of Irrigation Interval

It can be observed from **Figure 5** that when the irrigation interval becomes greater than 5 days the reduction in effective rainfall is greater than when the interval is shorter. Though it is clear that a smaller interval results in more saving of irrigation water, it is associated with a greater number of irrigation practices, as can be seen from **Figure 8**. Thus, it consumes more time and labor, and makes the irrigation expensive when the irrigation source is not easily accessible. From **Figure 8**, it is also seen that the number of irrigation practices is reduced rapidly when the irrigation interval is raised from 1 to 5 days, but beyond 5 days the effect is negligible. From the rainfall effectivity point of view, at short irrigation intervals (up to 4 to 5 days), the saving in irrigation water is not much as compared to the reduction in irrigation application times. Thus, considering both the aspects, it seems that an irrigation interval of 5 to 6 days is most suitable and economical.

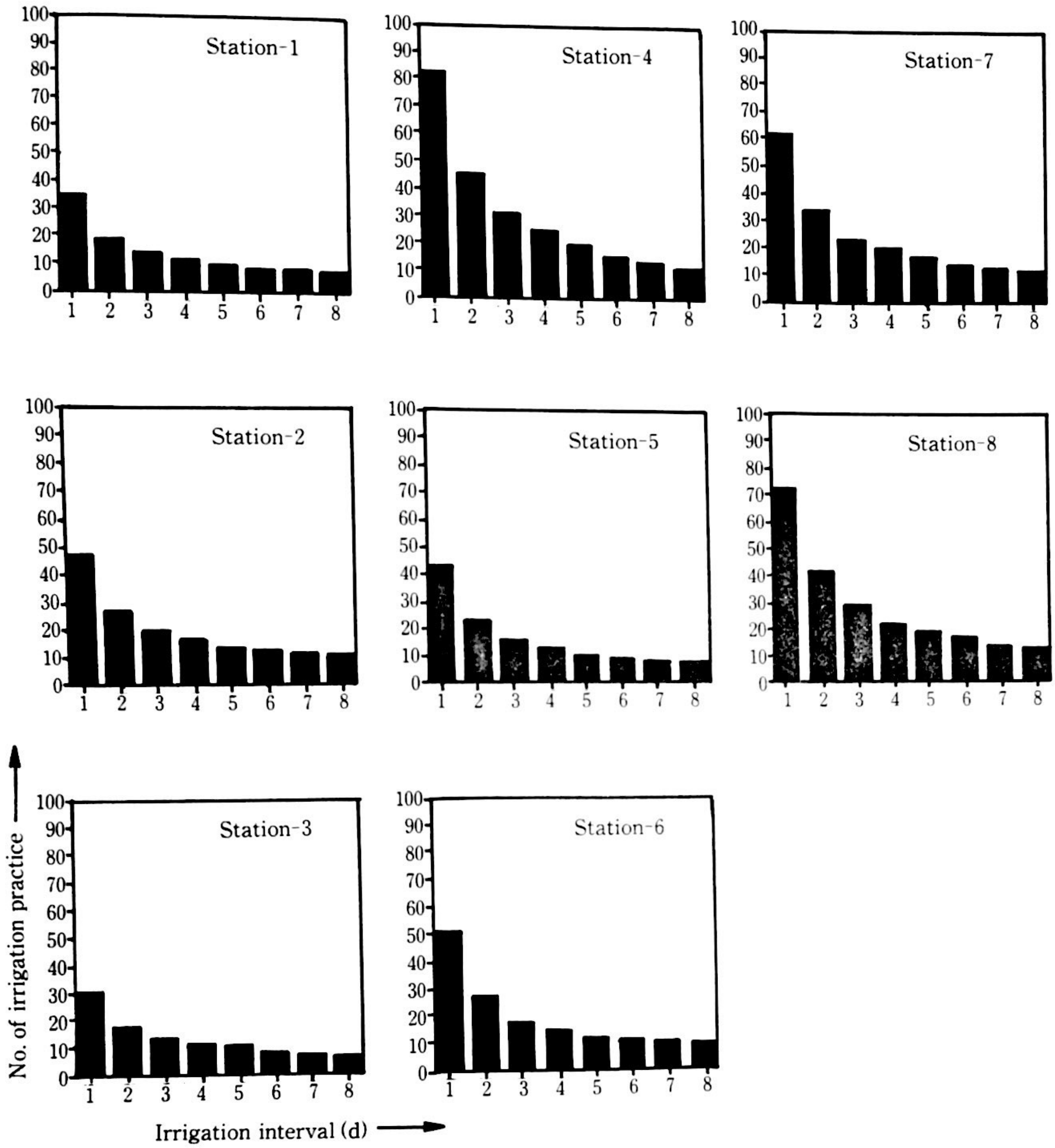

Figure 8 Effect of irrigation interval on number of irrigation practices (at a return period of 5 years, 4 mm/d percolation rate and 100 mm ponding depth)

IV. Conclusions

Based on the outcome of our experiment and simulation, the following conclusions can be drawn for Thailand:

1. Interception amount is found to be within the range of 0 to 2.5 mm, but is very significant if the distribution of rainfall throughout the growing season is uniform. It rises as high as 80 mm during the entire growing season in such cases.
2. Rainfall of less than 600 mm during the growing season is 95 to 100% effective, and with further increase in rainfall the effectivity is reduced.
3. Ponding depth has a strong influence on effective rainfall. But increase in the ponding depth beyond 150 mm at a percolation rate of 4 to 6 mm/d does not

make much significant difference. Also taking the suitable limit of ponding depth for paddy into consideration, it is suggested that the allowable ponding depth of 120 to 150 mm is ideal.

4. Irrigation interval has a strong impact on effective rainfall. The results of the simulation show that with a 1- to 4-day irrigation interval, the effect in saving more rainfall is not great compared to the reduction in irrigation application times. But with a 5-to 6-day irrigation interval the effect is just the reverse. This suggests an irrigation interval of 5 to 6 days for efficient and ecomomical irrigation.

5. A nomogram which shows composite effect of different factors on effective rainfall is prepared for station 4 at a return period of 5 years. The amount of effective rainfall for the entire season can be estimated easily using the nomogram.

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