벼 湛水灌漑組職에 대한 圃場 灌漑效率의 評價

Evaluating Field Application Efficiency for Flooded Rice Irrigation Systems

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摘 要

벼 湛水 灌漑 組織에 대한 効率 計算에 있어서 入力은 灌漑水量과 總降雨量이고 出力은 蒸發散 및 浸透損失의 合이 된다. 그러나 最近에는 入力을 灌漑水量으로, 出力은 蒸發散 및 浸透損失로 부터 有效雨量을 뺀 값으로 定義하고 있다. 비록 後者의 方法이 前者보다는 실제 논조건에 더 부합된 計算方法이기는 하지만 아직도 許容湛水深 유지에 必要한 灌漑水量, 各種生育期에서의 湛水深의 變化, 栽培方法에 따른 湛水深의 차이 등이 고려되지 않고 있다.

本 研究에서는 이와같은 벼 灌漑効率 計算의 單純化가 圃場灌漑効率의 精度와 適正度에 어떠한 영향을 미치는가를 檢討하고, 그러한 効果의 크기와 성질을 다음과 같이 2단계로 調査하였다. 첫째, 논에서의 日別물수지조건을 기본으로 하여 灌漑効率 計算模型이 개발되었으며, 이전 効率計算에서 省略된 모든 要因이 고려되었다. 둘째, 개발된 模型을 利用하여 圃場灌漑効率을 계산하고 그 결과를 재래방법으로 계산된 값들과 비교하였다.

本 研究는 아직까지 불충분한 것으로 간주되어 왔던 논 灌漑組織의 圃場 灌漑効率에 대한 몇가지 흥미있는 様相을 밝힌 것으로서 기본자료는 1985年 반월관개지구에서 수집된 것을 이용하였다.

1. 計算模型은 포괄적인 것이므로 어떤 地方의 수집자료라도 適用할 수 있다. 모형의 計算結果를 볼때 灌漑効率과 消費水量 사이에 接近된 경향을 보여 주므로서 모형개발의 目標를 잘 충족시켜 주고 있는 것으로 판단된다.

2. 模型에서의 計算 時間間隔은 制限的이지는 않지만 중요하며, 比較分析이 關聯된 경우에는 주의하여 間隔을 選擇해야 한다. 계산결과를 보면 짧은 시간간격이 灌漑効率이 아주 크거나 작은 기간을 더 잘 反映하는 것으로 나타났다.

3. 논의 圃場 灌漑効率을 計算함에 있어서 各 灌漑期의 初期貯水量과 許容湛水深을 무시한 効率計算은 큰 오차를 나타냈다. 반월관개지구에서 週間포장 관개효율은 −58%～16%로 오차범위가 관측되었다.

4. 논 貯水量 및 許用湛水量을 고려한 것과 고려하지 않은 것 사이의 相以性이나 有意的

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인 관계는 없었다. 그러나 研究結果에 의하면 前者의 方法이 效率測定에 있어서 더 적합한 것으로 판단되었다.

5. 開發된 模型은 논灌漑의 物理的 측면과 管理目標 모두를 고려한 것이므로 計算된 效率은 벼 生育 各 段階에서의 效率 比較에 양호한 方法임을 알 수 있다.

I. INTRODUCTION

Evaluation of irrigation efficiencies requires that the input and output components of the efficiency quotient be clearly defined. Input is generally taken as the irrigation supply and output as the necessary and beneficial uses of water. The definition of input is simple and clear. However, for the output the purpose and needs of irrigation must be understood before the necessary and beneficial uses of water can be defined.

In flooded rice irrigation, the crop is grown under submerged conditions. The levels of maximum permissible submergence(MPS) at each growth stage of the crop vary from locality to locality and often represent a compromise between the amounts of water availible for irrigation, the availible labor for water management, water regulating structures at farm level, and the rice variety grown.[5)] [18)]

In the operation and management of these flooded rice irrigation systems, the amounts of water required to achieve the desired levels of submergence are usually planned for and are included in the irrigation water supply schedules alongside the estimated requirements for evapotranspiration(ET) and seepage and percolation(SP) losses. Where raising the level of submergence is involved, the amounts of water used to raise it are considered beneficially used and cannot logically be ignored when counting the necessary and beneficial uses of water in the system. However, the water applied into paddy storage in excess of the maximum permissible submergence and which are not stored for later ET and SP usage during the period under consideration, must be considered a waste together with other system wastes which result from inefficient operation and management of the system. The physical characteristics of the system and the skill and care of the irrigator are the principal factors influencing the levels of these wastes and hence the system performance.

As the demand for water between competitive uses increases, there is a growing awareness for the need of improved irrigation performance at field level. This need calls for an effective method of assessing the efficiency with which irrigation water from the supply canal is being applied to the field to meet the net water requirements. This efficiency is by definition the field application efficiency,[5)] and it can be used to determine how effectively a system can be operated and whether it can be improved, to provide information to assist engineers in designing other systems, and for comparison of the performance of various systems or operation procedures.

A number of methods have been used to evaluate the field application efficiency in lowland rice irrigation systems.[4)] [14)] [20)]These methods are based on the perspective held by many that the only water requirements for lowland rice are those of evapotranspiration and seepage and percolation lossess.[2)] [4)] [9)] [11)] This view ignores the irrigation supply used for permissible submergence (PS). The methods also provide no allowance in their computations to account for the paddy surface storages present in or on the paddy at the start of each appliction operation (daily operations), the changing submergence requirements at different growth periods of the crop, and the differences in submergence requirements between different rice cultural practices. However in practice, it is known that the levels of paddy submergences do vary during the various crop growth stages as well as between different rice cultural practices. Under these circumstances, unless a comprehensive account of the irrigation inflow, useful paddy storage changes, and outflows is made in the computation of efficiencies, the adequacy and accuracy of the numerical values obtained as a measure of the actual field appliction efficiency may be questionable.

In view of the inherent limitations in the present efficiency evalution methods, this study was aimed to develop a computational procedure that would bring into account the paddy storages present at the start of application opertion, submergence use of irrigation supply, and the variations in submergence requirements at different crop growth stages and under different rice cultural practices. Then using the model developed, to investigate the nature and magnitude of the effects of these three factors may have upon the numerical values of the computed efficiencies. The specific objectives were as follows;

1. To develop a computational model for the calculation of flooded rice irrigation field appliction efficiency that makes allowance in the computation to account for the paddy surface storage present at the start of application operation, irrigation supply used for permissible submergence requirements and changing submergence requirements at different crop growth periods, in addition to the normally accepted considerations for evapotranspiration, seepage and percolation, rainfall contribution and irrigation supply.

2. By using the developed computational model, to determine the nature and magnitude of the effect of omission of the paddy storage present at the start of application operation and the amount of water used for permissible submergence in the computation of efficiencies, may have upon the numerical values of the computed efficiencies.

Ⅱ. RESEARCH METHODOLOGY

Site

The study was conducted at the Banweol irrigation area in Korea during the 1985 crop season. The irrigated area covered 408 hectares of cultivated paddy land. The source of irrigation water was a reservoir located at the upper boundary of the command area. For the purpose of this study, a mid-section of the command area was used. It consisted of some 7.2 hectares located in between the main field supply canal and the main field drainage channel. Water was supplied to individual paddies from field ditches which were fed directly from the main canal through check gates. The field ditches served a dual purpose of supply and drainage, and discharged into the drainage channel running along the lower boundary of the field.

Sources of Data

The data used in this study were obtained from and through a combination of field measurements, estimations, field observations, and from published materials and documents.

Field measurement -The field mesurements consisted of irrigation inflow into the site, paddy submergence water depths and rainfall. Suitably selected and installed rectangular cut-throat flumes were used to measure the irrigation inflows at points F1, F2 and F3.(see Fig. 1) The paddy submergence depths were measured using fixed staff gauges installed in each paddy. Rainfall(RF) measurements were made at Banweol area.

Estimations -Conservative estimates of seepage and percolation losses and evapotranspiration were made. The percolation losses were estimated from infiltrometer measurements. The infiltrometers were carefully installed at selected places which were representative of soil types and topographical conditions. Based on the relative sizes of different soil types, weighted average percolation rates were determined. These rates were multiplied by a correction factors to account for the proportions of paddies that had no standing water and assumed to have negligible percolation losses. Evapotranspiration measurements taken at the Experimental Crop Farm, College of Agriculture, Seoul National University[6]were taken a good estimates of the actual evapotranspiration losses at Banweol.

Field observation -Field observations were made on the operational procedures of water application, paddy water conditions, sources of system wastes(WST) and the general farming activities.

Published materials and documents

Information on the operational procedures and the maximum permissible submergences for Banweol irrigation area were obtained from official documents of the Suweon Farmland Improvement Association, Banweol branch office. Information on soil types was obtained form the detailed soil map.[13]

Method of Analysis

The procedure consisted of two steps. First, a computational model that made a comprehensive account of the paddy irrigation inflows, useful surface storage changes, and outflows in the calculation of lowland field application efficiencies was developed. The model was designed to bring into consideration the paddy storage present at the start of irrigation application operations (daily operations), the irrigation supply used for permissible submergence, and the variations in submergence requirements in addition to the considerations of evapotranspiration losses, seepage and percolation losses, rainfall contribution and irrigation supply which have been given due consideration in the previously developed evaluation methods. Different efficiency intervals were considered to determine the lengths of interval that would adequately represent the system operational conditions.

Second, the model was used to compute the field appliction efficiencies for the Banweol conditions that included the standard submergence schedule recommended for the area.These efficiences were cnsidered to more closely reflect the actual field application efficiencies They were compared with the crresponding field application efficiency values obtained from Eq. 1[3]

$$Ea=\frac{(ET+SP)-ER}{IR}\times 100 \qquad (1)$$

Where, Ea=field application efficiency in %
ER=effective rainfall in mm / day
IR=irrigation supply in mm / day

This expression is considered more sound than

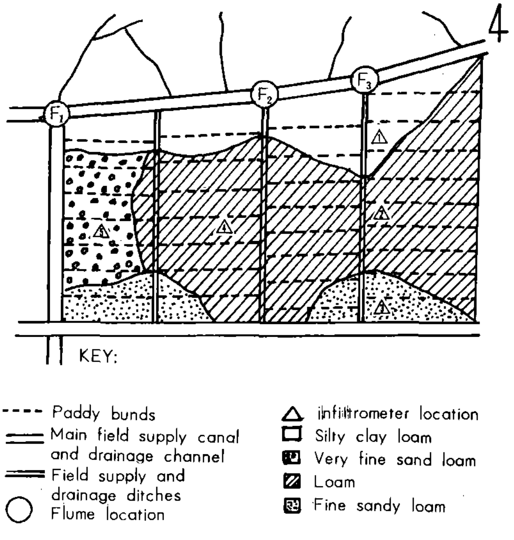


Fig. 1. Arrangement of the Paddy Fields relative to the Main Canal, Field Ditches and Drainage Channel; Distribution of Soil Types at the Site and Location of the Flumes for Inflow Measurement.

other existing field application evaluation procedures.[4] The equation is basically of the same dimensions as the model(Eq. 9) except that it does not make allowance in its calculations to account for the paddy storage present at the start of application operation and supply used for submergence requirements.

The comparison between the two efficiencies was formulated on the null hypothesis that the omissions of the paddy storage and submergence use in the calculation of efficiencies do not result in significant differences in the values of efficiencies obtained. Non parametric statistical tests were employed because the individual numerical values of the efficiencies were not drawn from a population and could not be expected to follow the normal distribution function. Rather statistical tests were carried out to compare the ranges of efficiency values. the difference(D), mean efficiencies, relative variations with respect to time after transplanting, and the distribution of low and high periods of application for different efficiency intervals.

Ⅲ. THE COMPUTATIONAL MODEL

Model Development

Development of the efficiency computational model is based on the consideration of daily operation of the water balance within the paddy fields. The model consists of five parameters which are formulated to estimate the net water requirements, the system wastes and calculate the field application efficiency.

Parameters of the model -the five parameters, total water supply, evapotranspiration, seepage and percolation, permissible submergence and paddy surface storage carried forward, considered in the development of the model are as follows:

The total water supply to the paddy is the sum of irrigation plus effective rainfall. Effective rainfall means the total rainfall minus the excessive rainfall which can not be stored or used in the paddy field.[7)][16)] For the purpose of this study, a conservative estimate of the daily effective rainfall was made using a modified version of the Free Board Model described as Eq. 2.[16)]

$$ASTO_n = STMAX - STO_{n-1} + ET_n + SP_n \qquad (2)$$

$$STMAX = 125\text{mm}$$

$$\text{if } RF_n < ASTO_n : ER_n = RF_n$$

$$\text{if } RF_n \geq ASTO_n : ER_n = ASTO_n$$

where, $ASTO_n$ =available storage capacity at end of day n in mm

STO_{n-1} =storage in paddy field at the end of previous day in mm

STMAX =maximum storage capacity of the paddy in mm

n =day for which effective rainfall is determined

Evapotranspiration in lowland paddy is the combined effect of evaporation from the moist soil surface or open water surface and transpiraton and evaporation from plant leaves.[15)] In this study estimates of ET were made from lysimetry measurements.

Seepage and percolation losses, usually referred together, account for the horizontal and vertical movement, respectively, of water into the soil. These SP losses can not be reduced materially by alternative water management programs and are therefore considered as a soil requirement for water and a necessary part of the irrigation requirement for flooded rice irrigation. In paddies that are centrally located within a large irrigated area, seepage losses are approximately offset by incoming seepage from higher paddies. Net loss from paddy-to-paddy seepage results only from the last paddy of the system which is usually located along a drain or unplanted area acting as a sink for the entire system. Percolation losses are more stable and predictable than seepage losses. The factors which have been found to have important impact on SP losses are the drainage channel density[20)], drying and cracking of the soil[10)], soil texture[1)]and soil puddling[8)].

Lowland rice is grown under submerged conditions. The maximum permissible submergence depths recommended for each growth stage will vary with the local conditions and crop variety. Any submergence between zero and MPS is considered beneficially used or permissible submergences PS. That is $0 \leq PS \leq MPS$. The model converts the daily submergence levels or paddy surface storage into PS based on the following conditions.

$$\text{If } STO_n \geqq MPS_n;\ PS_n = MPS_n \quad (3)$$
$$\text{If } STO_n < MPS_n;\ PS_n = STO_n$$

where, n=day under conideration

In flooded rice irrigation systems, there is usually some paddy surface storage(STO_{n-1}) present on or in the paddy at the start of the irrigation application operation. The levels of STO_{n-1} will depend much on the type of irrigation method in use. Irrigation methods in lowland rice can be devided into three categories : (a) Continuous flowing irrigation where there is continuous flooding and the water is allowed to overflow continuously by opening both the inlets and outlets in the paddy field, (b) continuous submergence irrigation where there is continuous flooding and irrigation water is supplied periodically to correspond with the water consumption of a given paddy field, and (c) intermittent irrigation where water is supplied into the paddy to a certain depth, keeping the inlet closed for a few days until the water is consumed, and then resuming the water supply. [12) 18) 19)]

Water requirements -The daily water requirements (WR) in flooded rice irrigation depends on the differences between the sum of evapotranspiration, seepage and percolation and permissible submergences, and the amount of paddy surface storage present in or on the paddy at the begining of the day. This can be expressed by a simplified equation as follows.

$$WR_n = ET_n + SP_n + PS_n - STO_{n-1} \quad (4)$$

If part of the WR is met from rainfall, then the net water requirement (NWR) can be expressed as follows.

$$NWR_n = ET_n + SP_n + PS_n - STO_{n-1} - ER_n \quad (5)$$

When PSn is equal to STO_{n-1}, the NWR_n is equal to the sum of ET_n and SP_n less ER which is the same as the water requirement in Eq. 1. However this is not always true as PS_n and STO_{n-1} are rarely equal. The inequality of PS_n and STO_{n-1} creates five different water requirement conditions determined mainly by the level by which STO_{n-1} falls short of or exceeds

Table-1 Water requirement conditions in flooded rice irrigation systems .

Conditions	Net water requirement (NWR)
$(STO_{n-1} - PSn) = 0$	NWR=ET n+SPn−ERn
$(STO_{n-1} - PSn) > (ETn+SPn-ERn) > 0$	NWR=0
$(STO_{n-1} - PSn) = (ETn+SPn-ERn) > 0$	NWR=0
$(STO_{n-1} - PSn) < (ETn+SPn-ERn) > 0$	NWR=ETn+SPn−ERn−△Sn*
$(STO_{n-1} - PSn) < 0$	NWR=ETn+SPn−ERn+△Sn*

*$\triangle Sn = STO_{n-1} - PSn$

the permissble submergence. These conditions are summarized in the Table-1.

Ststym wastes -The most obvious system wastes (WST) are those occuring from losses in the field conveyance system,[17] seepage and leakage during the time water is being transfered from the supply channel to the paddy, surface runoff resulting from excess field application, leakages in the paddy bunds and through flow which is the water flowing down the field supply ditches to the drainage channel without being applied to the paddies. Another WST that may not be easily recognized is the paddy surface storage in excess of the maximum permissible submergence,(MPS) evapotranspiration(ET) and seepage and percolation (SP) requirements. Once the needs for MPS, ET and SP have been met, any additional irrigation water supplied to the field whether added to the paddy storage or not must be considered a WST at the particular point of consideration, and should be added to the list of system wastes accordingly.

Field application efficiency calculation -Efficiency in irrigation can be expressed in a general form as follows.

$$\text{Efficiency}(\%)=\frac{\text{Water required}}{\text{Water supplied}}\times 100 \quad (6)$$

In flooded rice irrigation the net water requirement, NWR, for field application is determined as outlined in previous section. The water supply is irrigation. The efficiency equation for flooded rice field application can therefore be arranged as follows

$$Ea=\frac{NWR_n}{IR_n}\times 100 \qquad (7)$$

or

$$Ea=\frac{(ET_n+SP_n+PS_n-STO_{n-1}-ER_n)}{IR_n}\times 100 \qquad (8)$$

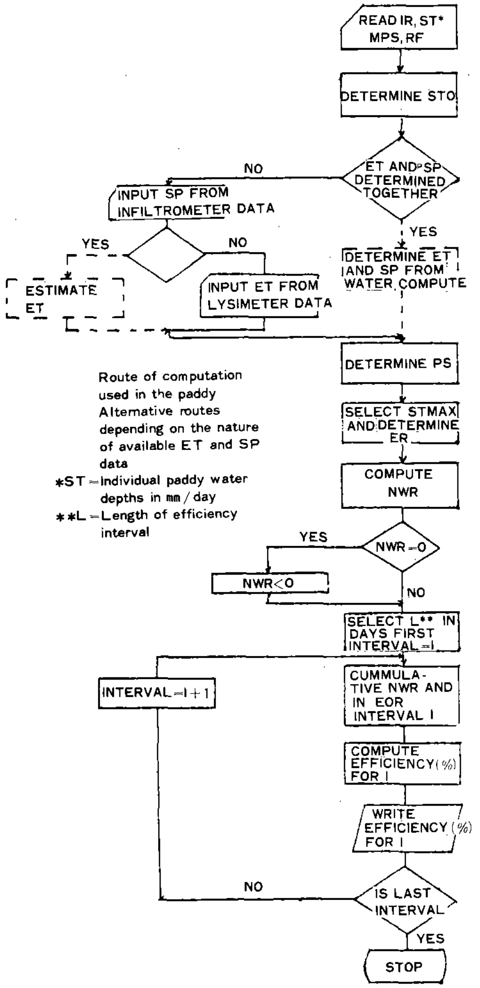
For the computation of Ea for a period of given number of days, the equation takes the following general form.

$$Ea=\left(\sum_{i}^{t}\{[ET_n+SP_n+PS_n-STO_{n-1}-ER_n]\geqq 0\}_i\right)/\left(\sum_{i}^{t}IR_i\right)\times 100 \qquad (9)$$

Where i is the first day in the period and t is the last day of the period. It is important to note that the equation considers the sum of daily net water requirements (NWR) for the period of analysis rather than the lumped net water requirement for the period. This is because in paddy irrigation operation, the irrigation supply is subject to daily adjustments depending on the prevailing water requirement conditions in or on the paddie. The equation also takes into account two factors that have been underestimated in earlier evaluation procedures. These are the amounts of paddy surface storage at the begining of the day under consideration (STO_{n-1}) and the amount of water used for beneficial permissible submergence(PS). Thus it meets the basic requirements of the proposed computational model and was therefore used for the computation of the field application efficiencies.

Model Operation

The model operation is possible once the maximum permissible submergence (MPS) and the maximum storage capacities of the paddies (STMAX) are specified for each site. Rainfall (RF), irrigation supply (IR), daily paddy surface water depths (STO), evapotranspiration (ET) losses and seepage and percolation (SP) losses are provided as input data. The effective rainfall (ER) and permissible submergence (PS) are estmimated from the input data. These parametes are then combined into the form expressed in Eq. 9 for the computation of field application efficiencies. The procedure is simple and straight forward where a single paddy is involved. However, it is complicated for field situations where a large number of paddies are involved because of the many different water requirement conditions occuring all over the paddies. Two appoaches were employed to aleviate this problem. One is to determine the daily net water requirements for each paddy involved and then sum them up to find the daily net water requirement for the field. This method is more accurate but it becomes complicated when too many paddies are involved. The second approach takes weighted average paddy water depths and treats the whole field as a single unit. Test results showed that the difference between the efficiencies obtained by these two approaches were not significantly different when a large number of paddies are involved. It can also be argued that since we are concerned with water use in the whole field and not water distribution between different paddy fields, the second approach is adequate for the purposes of field application efficiency evaluations, and was used in this study.



Route of computation used in the paddy
Alternative routes depending on the nature of available ET and SP data
*ST = Individual paddy water depths in mm / day
**L = Length of efficiency interval

Fig. 2. Flow Chart for Efficiency Model Computation.

The computation based on the flow chart illustrated in Fig.2 was carried out using digital computers. Field application efficiencies expressed in percentages were obtained as output.

Ⅳ. RESULTS AND DISCUSSION

Results of Model Computation

Efficiencies versus paddy water status -The model considerd the complete water status in the paddies and brought into account the two volumes of water that have been neglected in the previously developed efficiency evaluation procedures. These are: (1) The volume of water already present in the paddy storage at the start of application operation (STO_{n-1}) and (2) the volume of water going into paddy sruface storage for permissible submergence use, $(PS_n - STO_{n-1}) > 0$. The numerical values of the efficiencies obtained followed certain trends related to the predetermined paddy water storage and submergence use conditions. These are summarized in Table -2.

These trends are consistent with the net water requirement conditions described in Table 1 and the expected efficiencies according to the definition in Eq. 6. Under the general efficiency definition, it can be expected that there would be some direct relationship between the input and the numerical values of efficiencies. However, in this case, no absolute relationship between the computed efficiencies and irrigation supply were obtained. The correlation coefficient between Ea and IR were - 0.37, -0.47, -0.18 and -0.52 for efficiency intervals of 4, 7, 10 and 13days respectively. The low correlation between IR and Ea can be attributed to the many variables that determine the NWR Eq. 5 and hence the Ea values. These results allow the following general inferences to be made about lowland field application efficiencies.

Diverting irrigation water to the field when there is excess field surface storage sufficient to meet the needs of ET and SP losses results in 0% field application efficiency no matter how small or large the volume of irrigation water applied. This is because water is applied against zero demand.

When there is no excess paddy storage, but the existing permissible submergence is depleted at rates sufficient to meet ET and SP losses, any irrigation supply during the same period results in 0% field application efficiency because irrigation water is supplied against zero utilization.

The field application efficiencies are greater than 0%, only when the irrigation supply is used to meet partial or total water requirements for ET and SP losses and PS uses.

Efficiency versus efficiency interval -Comparison of efficiencies (Ea) determined for 4, 7, 10 and 13 days efficiency intervals for the period from 11 to 101 days after rice transplanting are summarized in Table-3.

These results suggest that the time base for efficiency analysis is not critical for model computation of the mean efficiencies for the whole crop season, but are important when the efficiency for the intervals are considered seperately. Increasing the length of efficiency intervals introduces an averaging effect that combines the low and high efficiencies obtained within the interval with resultant reductions in the ranges of efficiencies obtained and their relative variations. No significant change in the mean efficiency with respect to changes in the efficiency interval were observed. A clear reflection of the inefficient and efficient periods of water application are obtained by choosing shorter efficiency intervals to avoid the averaging effects introduced by the longer intervals. The lengths of efficiency intervals chosen should be determined by the level of accuracy required, convenicence and cost.

Effects of Paddy Storage and Submergence Use

Efficiency computaions based on the computational model Eq. 1 and Eq. 9 assumes two different water management practices in applying water to the field to meet the purposes and needs of flooded rice irrigation. The first case assumes a management practice where before water is applied to the field, an assessment is made of the water storage already present in the field in order to determine if and how much water is required to meet the purposes and needs of flooded rice irrigation which includes submergence use, ET losses and SP losses. The second case assumes a management practice where water is applied to the field to meet only the ET and SP requirements. With this practice no consideration is made of the paddy storages present at the start of the application operation(daily operations), or the irrigation supply beneficially used to raise the paddy submergence to some desired level.

There seems to have been no previous attempts by researchers to evaluate how the omissions of paddy storage present at the start of application operation and water used for submergence would affect the nemerical values of efficiencies obtained. The results of this study which was aimed to investigate these effects showed some very interesting features about paddy irrigation efficiencies. Through these results are based on the conditions that were

Table-2. Relations between Field Application Efficiencies and Paddy Water Status Conditions.

Paddy Water Status Conditions	Efficiency (Ea)
$(STO_{n-1} - PS_n) = 0$	$Ea > 0$
$(STO_{n-1} - PS_n) > (ET_n + SP_n - ER_n) > 0$	$Ea = 0$
$(STO_{n-1} - PS_n) = (ET_n + SP_n - ER_n) > 0$	$Ea = 0$
$(STO_{n-1} - PS_n) < (ET_n + SP_n - ER_n) > 0$	$Ea > 0$
$(STO_{n-1} - PS_n) < 0$	$Ea > 0$

Table-3 Field Application Efficiencies vs. Efficiency Intervals.

Efficiency Interval (days)	Efficiencies (%)		Coefficient of Variation (%)
	Range	Mean	
4	0−81	33.7	64
7	6−66	32.5	66
10	8−54	29.5	54
13	13−56	30.9	56

Table-4. Summary of Comparison between Efficiencies(Eal) Computed with Allowance for Paddy Surface Storage and Submergence Use and the Efficiencies(Ea2) Computed without These Allowances.

〔a〕 Range of Eal and Ea2 values in per-percentage

Method of Computation	Efficiency Interval			
	4 days	7 days	10days	13days
Ea 1	0−81	6−66	8−54	13−56
Ea 2	0−72	0−55	0−48	0−38

〔b〕 Range of differences between Eal an Ea2 in percentage

Dilference (D)	Efficiency Interval			
	4 days	7 days	10days	13days
Ea 1 − Ea 2	−30−−62	−16−58	−15−42	−6−28

〔c〕 Percentage of time that difference(D) is equal or more than 10%, 20% and 30%

Range of Differences (D%)	Efficiency Interval			
	4 days	7 days	10days	13days
$-10 \leqq D \geqq 10$	64	69	67	43
$-20 \leqq D \geqq 20$	32	23	22	29
$-30 \leqq D \geqq 00$	14	15	22	0

〔d〕 Mean efficiencies computed for the total period of analysis

Mean Efficiency	Efficiency Interval			
	4 days	7 days	10days	13days
Mean of Ea 1	34%	33%	30%	31%
Mean of Ea 2	26%	18%	17%	18%

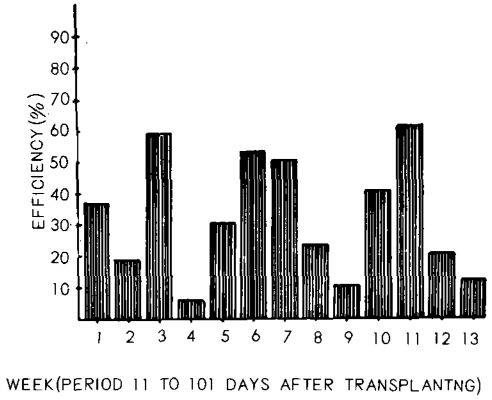
〔e〕 Relative variation(CV)* with respect to days after transplanting

Efficiency	Efficiency Interval			
	4 days	7 days	10days	13days
Ea 1	64	66	54	56
Ea 2	97	104	120	96

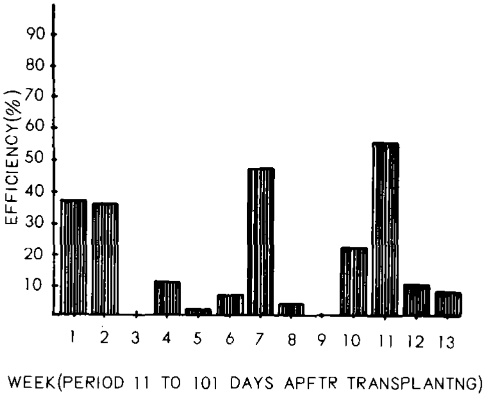
*CV = Coefficient of variation

〔f〕Relation between Eal and Ea2 and paddy water stutus

Paddy Water Status Conditions	Relation between Eal and Ea2
$(STO_{n-1} - PS_n) > (ET_n + SP_n - ER_n) > 0$	$Ea1 < Ea2$
$(STO_{n-1} - PS_n) = (ET_n + SP_n - ER_n) > 0$	$Ea1 < Ea2$
$(STO_{n-1} - PS_n) < (ET_n + SP_n - ER_n) > 0$	$Ea1 < Ea2$
$(STO_{n-1} - PS_n) = 0$	$Ea1 = Ea2$
$(STO_{n-1} - PS_n) < 0$	$Ea1 > Ea2$



a) DISTRIBUTION OF Ea 1*



b) DISTRIBUTION OF Ea 2**

* Eal= Model computation, ** Ea2= eqation 1. computation

Fig. 3. Distribution of Weekly Field Application Efficiencies with respect to Days after Transplanting: Contrast between Eal and Ea2.

measured at Banweol, the nature of these effects may be of general application.

For the purposes of this discussion, the efficiencies obtained from the model computation have been designated Eal and those obtained from the Eq. 1 designated Ea2. The results of the comparison between Eal and Ea2 are summarized in Table-4.

The range of weekly Eal and Ea2 were 6 – 66 % and 0 – 55 % respectively. These ranges increased with decreasing lengths of efficiency interval and vice versa (Table-4[a]). Although these ranges seem to lie within the same limits, their distributions and variations witin the limits were quite different. The points of low and high efficiencies did not necessarily coincide in the two cases. For example, the diffeerences between the corresponding values of Eal and Ea2 ranged from - 16 to 58 %. This range increased with decreasing efficiency interval and vice versa (Table-4[b]). When the whole period of analysis was considered, the percentage of times that the weekly Eal and Ea2 showed absolute differences equal or more than 10 %, 20 % and 30 % were 69 %, 23 % and 15 % respectively. This means that if a deviation from the actual efficiency of 10 % or more were not acceptable, then 69 % of the efficiencies calculated would be considered not acceptable and inaccurate. The same analogy can be applied to the other levels of deviations or efficiency intervals. The percentage of times that deviations of 10 %, 20 % and 30 % or more were recorded changed only slightly, but no trends were observed (Table-4[c]).

Other differences that were observed between the values of Eal and Ea2 were on their means computed for the whole period of analysis, their relative variations with respect to days after transplanting expressed in percentage coefficients of variations, and the distributions of periods of low and high efficiencies during the total period of analysis. The weekly mean for Eal was 33 % and for Ea2 18 %. These mean values showed no significant changes with changes in efficiency intervals (Table-4[d]). The relative variations for weekly Eal and Ea2 were 66 % and 104 % respectively and showed no trend with the variation in efficiency intervals (Table-4[e]). The differences in the distributions of periods of low and high weekly Eal and Ea2 are illustrated in Fig. 3.

These results show no simularities or systematic relationships between the corresponding values of Eal and Ea2. The only relationship between them were the trends in which their relative values varied depending on the paddy water status conditions as shown in(Table-4 [f]). These differences between Ea1 and Ea2 are big enough to lead to serious misrepresentation and misinterpretation of te actual performance of the system if Ea2 is used for efficiency evaluation.

V. SUMMARY AND CONCLUSION

The general efficiency concept is the quotient of output and input. For flooded rice irrigation application efficiency the output has generally been taken as evapotranspiration loss plus seepage and percolation losses and input as irrigation supply plus total rainfall. More recently output has been defined as the sum of evapotranspiration losses and seepage and percolation losses less effective rainfall and input as irrigation supply. Although this later approach is claimed to be more sound than the former in reflecting the efficiency with which the management applied water to the field to meet the net irrigation requirements, it omits in its computation to account for the paddy surface storage present in or on the paddy at the start of appliction operation, the amount of irrigation supply used for permissible submergence, the changing submergence requirements at different crop growth stages. The nature and magnitude of the effect these omissions may have upon the adequacy and accuracy of the computed efficiencies as a measure of the actual field application efficiency were investigated. The investigations were carried out in two stages.

Firstly, an efficiency computational model based on the daily operation of the water balance within the paddy field was developed. This model took account of all the ommisions in the previous methods in addition to the traditional considerations of evapotranspiration, seepage and percolation losses, irrigation supply and rainfall. Secondly, the model was used to compute the field application efficiencies and the results compared with the corresponding values obtained from computations using the previous method.

The results of this study based upon the data collected at Banweol irrigation area, 1985 crop season can be summarized as follws;

1. The computational model is general and can be applied to data collected in any locality. The results of model computation showed close correspondence between irrigation application efficiency and the actual water utilized for evapotranspiration, seepage and percolation losses and submergence uses. The results thus satisfied the stated goals of model development.

2. The time base for model computation is not limitative, but is important and must be selected carefully and specified where comparative analysis is involved. The results show that shorter intervals give better reflection of the periods of high and low water application efficiencies.

3. Neglecting to account for the paddy storage present at the start of each application operation (daily operations) and the amounts of water used for permissible submergence in the computation of lowland rice field application efficiencies can lead to large errors in the computed efficiencies. In Banweol irrigation area, the errors observed were in the range -58% to 16% for weekly field application efficiencies.

4. No similarity or systematic relationship was observed between the efficiencies computed with an allowance for paddy storage and submergence use and the efficiencies computed without these allowances. The results suggest that the later efficiencies are not an adequate estimate of the efficiency with which irrigation water is applied to the field to meet the desired

goals.

5. Since the model computation takes into account both the physical aspects and management goals of lowland rice irrigation, the computed efficiencies provides a better base for comparison between the efficiencies at different rice growth stages.

Reference

1. Bandopadhya, A. K. and R. Sahoo, 1972. Effect of water management practices on yield and changes in physical properties and loss of nutrients from soil. Indian J. Agri. Res.6(1): 27-32.
2. Bhyiyan, S. I., C. A. Khan and I. Islam, 1979. Irrigation system performance in Bangladesh: Two case studies. Paper presented at the 1979 summer meeting of ASAE and CSAE, Winnepeg, Canada.
3. Bhuiyan, S. I., 1980. Water allocation, distribution and use criteria for irrigation system design and management: Selected research findings. A Report on a planning workshop on irrigation water management. International Rice Research Institute, Laguna, Philippines, pp. 139-157.
4. Bhuiyan, S. I., 1981. Experiences in field research in irrigation system management in Philippines: some methodological issues. Paper presented at the International seminar on field research methodologies for improved irrigation systems management. Tamil Nadu Agricultural University, Combatore, India.
5. Bos, M. G., 1974. On irrigation efficiencies. International Institute for Land Reclamation and Improvement, Publication 19, Wageningen, Nederlands.
6. Chung, H. W. and et al., 1985. 作物消費水量算定方法의 定立. 서울 大學校 農科大學 附屬 農業開發研究所.
7. Dastane, N. G., 1974. Effective rainfall in irrigation agriculture, Irrigation and Drainage paper 25, FAO, Rome.
8. De Datta, S. K. and M. S. A. A. A. Kerim, 1974. Water and nitrogen economy of rainfed rice as affected by soil puddling. Soil Sci. Soc. Am., Proc. 138: 515-158.
9. Early, A. C., 1980. Irrigation evaluation procedures for flooded rice crops. Monitoring and evaluation manual: Diagnostic analysis of farm irrigation systems, Volume II. Water management synthesis project. Colorado State University, Fort Collins, Colorado, pp. 209-215.
10. Ghildyal, B. P., 1969. Soil management for increased water use efficiency by rice. Symposium on soil and water management. Hissar, India.
11. Giron, O. and T. H. Wichham, 1976. New techniques for measuring seepage and percolation and water use efficeincies in irrigated areas. Saturday seminar paper. International Rice Research Institute, Laguna, Philippine.
12. Hsu, Y. P., 1970. Water management in paddy fields. ASPAC, Food and Fertilizer Technology Center, Extension bulletin, No. 1.
13. Institute of Agricultural Science, 1973. Detailed Soil Map, Office of Rural Development, Korea.
14. IRRI. 1983. Annual Report. International Rice Research Institute, Laguna, Philippines. pp. 28-29.
15. Sahni, B. M. and A. C. Early, 1981. Alternative methods for determining water requirements for lowland paddy rice production. Philippine Agricultural Engineering Journal 12 (1): 6-10.
16. Sen, L. W. and T. H. Wickham, 1977. Field studies of effective rainfall for lowland rice. Paper presented at the PSAE Symposium on soils and water in Manila, Philippines.
17. Trout, T. J. and S. A. Bowers. 1981. Operational evaluation of village level irrigation

conveyance system. Trans. of ASAE.

18. Tsutsui, H. 1972a. water management and requirement for rice cultivation under different irrigation methods and cultivation techniques. Working Paper represented at the water management seminar, Manila. FAO Irrigation and Drainage Paper 12. FAO, Rome.
19. Tsutsui, H., 1972b. Water management for agriculture. Proceedings of the National Seminar on water management at the farm level, korea, pp. 7-17.
20. Wickham, T. H. and V. P. Singh, 1980, Water movement through wet soils. Soils and Rice, IRRI. Laguna, Philippines, pp. 338-358.