JARQ 26, 214-221 (1992)
TARC Report

Water Use Efficiency in a Tertiary Development Area in Low and Flat Paddy Land in the Tropics

Yoshinobu KITAMURA*, Kean Leng LOW and Tek Lip HOR****

* Research Division II, Tropical Agriculture Research Center (Tsukuba, Ibaraki, 305 Japan)
** Engineering Division, Muda Agricultural Development Authority
(Alor Setar, Kedah, Malaysia)

Abstract
Rapid saturation and flooding of paddy fields are essential for timely land preparation for the dry season (first season) crop when rice double cropping is adopted on flat lowland. Tertiary development was a priority project in the Muda area to facilitate water distribution and shorten the presaturation period by increasing the canal density. In order to evaluate the tertiary development properly, a simple method was devised for estimating the irrigation use efficiency and rainfall use efficiency.

Discipline: Irrigation, drainage and reclamation
Additional key words: irrigation requirement, irrigation use efficiency, presaturation requirement, rainfall use efficiency, rice double cropping

Introduction

Irrigation systems for the implementation of rice double cropping in the tropical monsoon areas of Southeast Asia are characterized by an extensive service area with inadequate terminal facilities. A series of major irrigation projects with a high potential for rice double cropping seems to have almost been completed in Southeast Asia. However, rice double cropping does not appear to have materialized as originally planned in those projects.

One of the main factors underlying the instability of rice double cropping is the considerable delay in the distribution of irrigation water for saturation and flooding of the paddy fields during the presaturation period of the first season crop due to the low canal density in the extremely flat topography, resulting in the increase of irrigation water loss. Moreover, the delay in presaturation causes erratic cropping schedules and requires the continuous presence of the rice plant, creating year-round food sources for insect pests, and increasing the occurrence of damage caused by diseases and insect pests.

In the Muda scheme, the tertiary development project has been implemented since 1976 so as to increase the canal density from a level of 10 m/ha to 30-35 m/ha[3]. The main purpose of this project is to improve water distribution and to decrease the water requirement by shortening the presaturation period.

However, there are few studies on the quantitative criteria for performance evaluation of the tertiary development. In order to provide technical information pertaining to the effect of the tertiary development project, a joint research program was carried out between the Muda Agricultural Development Authority (MADA) and the Tropical Agriculture

This is a report on the collaborative studies between the Tropical Agriculture Research Center, Japan, and the Muda Agricultural Development Authority, Malaysia.
* Present address: Department of Hydraulic Engineering, National Research Institute of Agricultural Engineering (Tsukuba, Ibaraki, 305 Japan)

Research Center (TARC). As a part of this research program, the authors studied the method for the evaluation of tertiary development based on on-site experiments in the irrigation service area A (ISA A), in the SCRBD5b block, in which tertiary development had already been completed in the scheme.

Study area

The ISA A, in the SCRBD5b block of the Muda scheme was selected as a study area. The Muda scheme, which covers an area of 126,000 ha, of which 96,000 ha are under the cultivation of paddy, is the largest rice double cropping area in Malaysia. After the completion of the Muda Irrigation Project (Muda I Project), which was implemented from 1966 to 1970, the area showed a potential for rice double cropping due to the construction of irrigation and drainage systems at a level of 10 m/ha in canal density. Tertiary development in the SCRBD5b irrigation block which was completed in 1982 is divided into 8 irrigation service areas (ISAs), i.e. ISAs A, B, C, . . ., H. The study area of ISA A, covering 136.8 ha, lies in the southwestern part of the Muda scheme and is located approximately 20 km south of Alor Setar. The general location of the area is shown in Fig. 1.

The study area is nearly flat but generally slopes downward from the south to the north, with ground levels ranging from +2.1 m MSL to +1.5 m MSL. The area is bounded to the south by the bund of the secondary canal SCRBD5b, to the east by the bund of the tertiary drain SD1/R2C, to the north by the bund of the tertiary drain SD1/R2C and to the west by the bund of the tertiary drain SD1/R2C3. The canal density of the study area is 24.6 m/ha and the drain density is 30 m/ha. A plan of the study area is shown in Fig. 2. The soil consists of marine alluvial clay of the Chengai Series, generally fertile[4]. This soil is considered to be highly suitable for paddy cultivation on account of its heavy texture, generally fairly high nutrient content and flat topography.

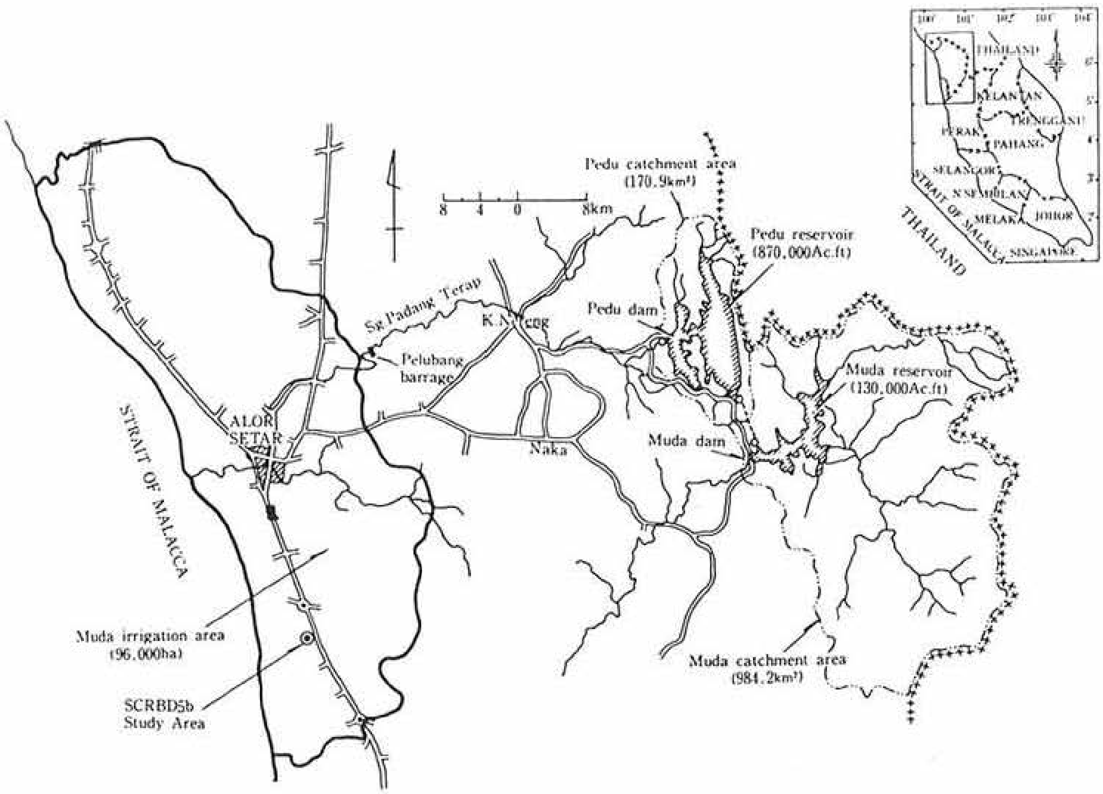

Fig. 1. General plan of Muda Irrigation Scheme

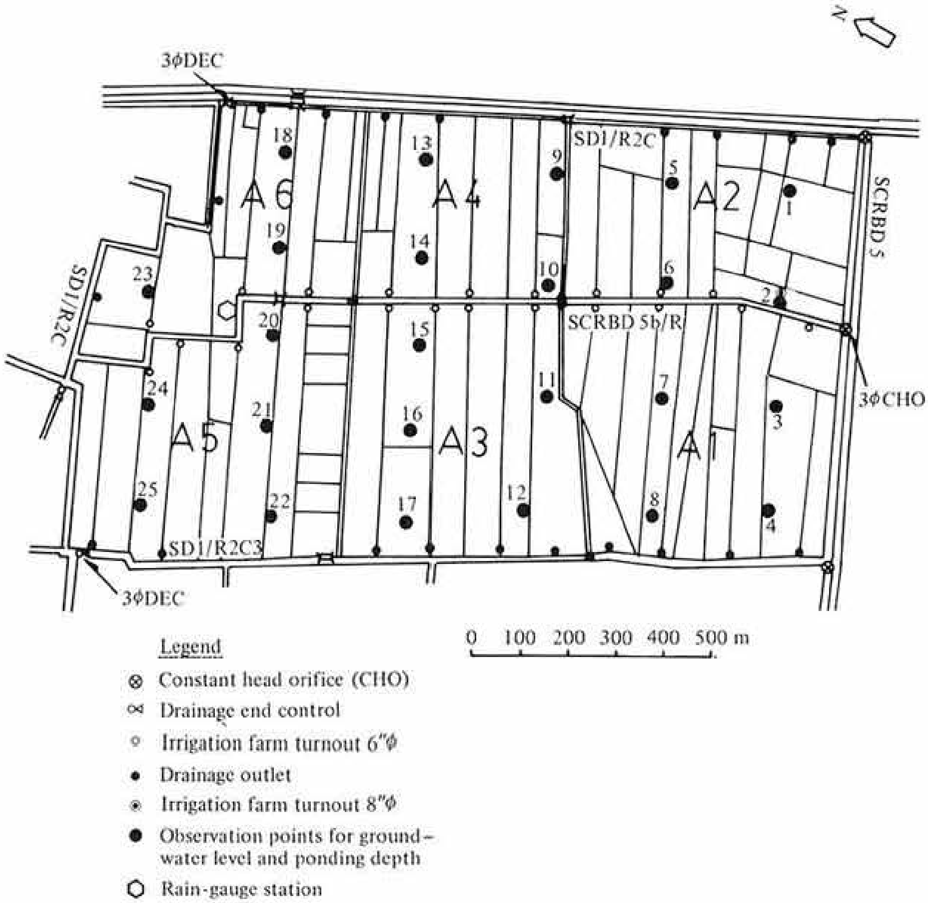

Fig. 2. Plan of ISA A, SCRBD5b (136.8 ha)

Materials and methods

1) Water balance

The irrigation supply was measured at the 3 feet-CHO (constant head orifice) offtake of SCRBD5b/R, in which the opening of the orifice gate was continuously monitored and the differential head at the orifice gate was continuously recorded using a differential head recorder designed by TARC. The calibration curve showing the relationship among gate opening, differential head and offtake discharge was adopted for the calculation of the water supply.

Groundwater level and ponding depth were calculated daily by manual measurements at 25 observation points which were distributed equally in the study area. It was assumed that the 25 observation points were representative of the whole study area in terms of groundwater level and ponding depth. The evaporation from the soil surface (Es) and the total existing water (TEW) can be estimated from the groundwater level and ponding depth based on field experiments carried out in the Telok Chengai Experimental Station[5]. In this study, TEW in the fields includes not only the standing water on the field surface but also the existing water in the soil from the surface down to the 100 cm depth level.

The water balance is expressed by the following equation:

$$IR + RF = \Delta TEW + ET + DR \quad \text{..............} (1)$$

where IR: irrigation supply (mm),

RF: rainfall (mm),
ΔTEW: variation of TEW in the field (mm),
ET: evapotranspiration (mm),
DR: drainage including seepage and percolation (mm), (percolation = outflow of groundwater − inflow of groundwater).

Out of the 5 factors composing the above equation, IR, RF, and ΔTEW were obtained by direct measurement. ET was calculated by multiplying the compound ET ratio by the pan-evaporation. DR is the only factor unknown in the above equation. Therefore DR can be calculated by Eq.(1).

2) Irrigation use efficiency and rainfall use efficiency

A simple method was applied for estimating from observed data the ratio of the water effectively used to the water supplied as a measure of water use efficiency.

This method is based on the assumption that the following theoretical linear relationship is valid:

$$Efi \cdot IR + Efr \cdot RF = \Delta TEW + ET + P = EUW \quad \cdots\cdots (2)$$

where Efi: irrigation use efficiency,
Efr: rainfall use efficiency,
EUW: effectively used water (mm),
P: percolation (mm).

In this paper, ET and P are considered to be unavoidable losses and included in the effectively used water (EUW) as well with the increment of TEW.

For estimating from the observed data the irrigation and rainfall use efficiency in relation to the presaturation, the following linear relationship was applied:

$$Epi \cdot IR + Epr \cdot RF = \Delta TEW \quad \cdots\cdots (3)$$

where Epi: irrigation use efficiency for ΔTEW,
Epr: rainfall use efficiency for ΔTEW.

Results and discussion

1) Water balance

Considering only the period in which water is required for paddy cultivation including the presaturation and supplementary periods, the water balance for the five cropping seasons (3 first seasons and 2 second seasons) is shown in Table 1[2]. The average annual consumptive use of water for paddy cultivation was 2,813 mm, of which 1,567 mm or 55.7% accounted for ET and 1,246 mm or 44.3% for DR. On the other hand, the average annual water supply was 2,777 mm, of which 908 mm or 32.7% was supplied by irrigation and 1,869 mm or 67.3% by rainfall. The deficit of 36 mm between supply and consumption was accounted for by TEW. The observed quantity of water irrigated for two crops was about 60% higher than that of the designed net irrigation requirement for two crops (582 mm)[1] although the amount of rainfall was 10% higher than in a normal year.

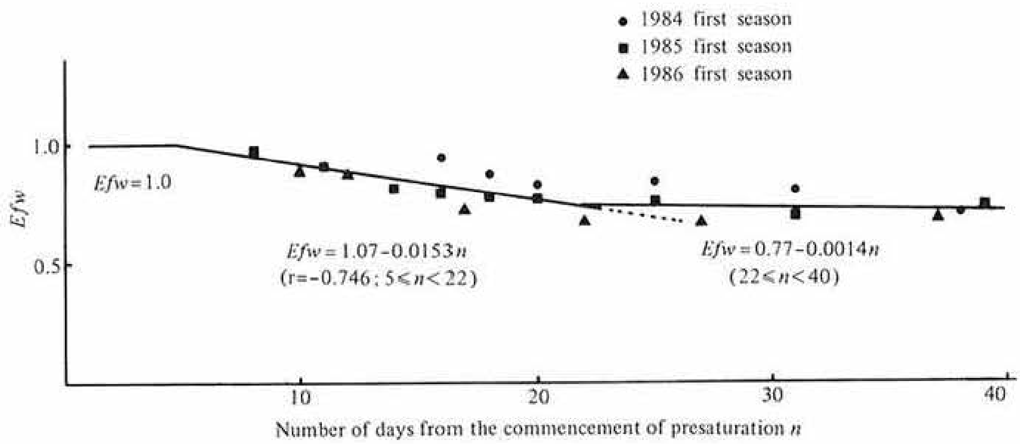

Fig. 3. Change of water use efficiency (Efw) during the presaturation period in ISA A, SCRBD5b[2]

Table 1. Water balance for double cropping in ISA A, SCRBD5b, Muda scheme, Malaysia[2)]

Season	Duration	(days)	Supply			Consumption		
			IR[d)]	RF[e)]	Total	ET[f)]	ΔTEW[g)]	DR[h)]
1984 first season		(184)	562	1,331	1,893	930	17	946
Presaturation[a)]	1 Mar. - 7 Apr.	(38)	349	136	485	149	163	173
Supplementary[b)]	8 Apr. - 30 Apr.	(23)	32	365	397	117	-33	312
Growth stage[c)]	1 May - 31 Aug.	(123)	181	830	1,011	664	-113	461
1984 second season		(152)	378	522	900	813	-103	190
Presaturation and supplementary	16 Sep. - 14 Oct.	(29)	120	94	214	141	18	55
Growth stage	15 Oct. - 14 Feb.	(123)	258	428	686	672	-121	135
1985 first season		(181)	623	1,082	1,705	803	78	824
Presaturation	1 Mar. - 16 Mar.	(16)	81	199	280	69	138	73
Supplementary	17 Mar. - 7 Apr.	(22)	165	37	202	142	-36	96
Growth stage	8 Apr. - 27 Aug.	(143)	377	846	1,223	592	-24	655
1985 second season		(153)	329	726	1,055	635	-79	499
Presaturation and supplementary	12 Sep. - 7 Oct.	(26)	23	236	259	99	57	103
Growth stage	8 Oct. - 11 Feb.	(127)	306	490	796	536	-136	396
1986 first season		(165)	478	1,322	1,800	795	71	934
Presaturation	15 Mar. - 2 Apr.	(19)	174	178	352	54	128	170
Supplementary	3 Apr. - 20 Apr.	(18)	1	135	136	104	16	16
Growth stage	21 Apr. - 26 Aug.	(128)	303	1,009	1,312	637	-73	748
Average of first seasons		(177)	554	1,245	1,799	843	55	901
Presaturation		(25)	201	171	372	91	142	139
Supplementary		(21)	66	179	245	121	-17	141
Growth stage		(131)	287	895	1,182	631	-70	621
Average of second seasons		(153)	354	624	978	724	-91	345
Presaturation and supplementary		(28)	72	165	237	120	38	79
Growth stage		(125)	282	459	741	604	-129	266
Total for two seasons		(330)	908	1,869	2,777	1,567	-36	1,246
Presaturation and supplementary		(74)	339	515	854	332	163	359
Growth stage		(256)	569	1,354	1,923	1,235	-199	887

a): Presaturation period; Period between onset of irrigation and the day when presaturation reaches 100%.
b): Supplementary period; Period between the day when presaturation reaches 100% and the day when 50% of direct sowing is completed.
c): Paddy growth stage; Period between the day when 50% of direct sowing is completed and 15 days before 90% of harvesting is completed.
d): Irrigation supply.
e): Rainfall.
f): Evapotranspiration.
g): Variation of total existing water in fields.
h): Drainage including seepage and percolation.

2) Irrigation use efficiency and rainfall use efficiency

(1) Presaturation period

[*Efi* and *Efr*]:

The analysis based on Eq. (2), revealed that the irrigation use efficiency and the rainfall use efficiency for *EUW* are almost equal during the presaturation period. The following equation was derived:

$$0.72 \cdot IR + 0.72 \cdot RF = \Delta TEW + ET + P \quad \text{........ (4)}$$

However, *Efi* and *Efr* change with the time after the onset of presaturation. Assuming that *Efi* equals *Efr*, both are represented by the water use efficiency (*Efw*) and expressed as follows:

$$Efw = (\Delta TEW + ET + P)/(IR + RF) \quad \text{........ (5)}$$

Based on the field experiments on *Efw* (Fig. 3), a linear relationship was obtained as follows:

$$Efw = 1.0 \quad (\text{when } n < 5)$$
$$Efw = 1.07 - 0.0153 \cdot n \ (\text{when } 5 \leq n < 22) \quad \text{.... (6)}$$
$$Efw = 0.77 - 0.0014 \cdot n \ (\text{when } 22 \leq n < 40)$$

(*Efw* is evaluated cumulatively from day 1)

where n: number of days from the onset of presaturation.

[*Epi* and *Epr*]:

By substituting the values of cumulative *IR*, *RF* and ΔTEW when 100% of the study area was presaturated in three seasons for Eq. (3), the following equations were obtained.

$$349.3 \cdot Epi + 135.7 \cdot Epr = 170.6$$
(1984 first cropping season)
$$81.4 \cdot Epi + 198.5 \cdot Epr = 137.9$$
(1985 first cropping season) .... (7)
$$174.3 \cdot Epi + 177.8 \cdot Epr = 144.3$$
(1986 first cropping season)

The optimum solutions of *Epi* and *Epr* were obtained by the method of least squares as follows:

$Epi = 0.26$, $Epr = 0.58$

Therefore, the following relationship was derived:

$$0.26 \cdot IR + 0.58 \cdot RF = \Delta TEW \quad \text{.................. (8)}$$

In Eq. (8), it is worth noting that *Epi* is far smaller than *Epr*, in contrast with the compound coefficients of *Efw*, as expressed by Eqs. (4) and (6). Therefore, the difference between Eq. (4) and Eq. (8) can be written as follows:

$$0.46 \cdot IR + 0.14 \cdot RF = ET + P \quad \text{.................... (9)}$$

The reason why the irrigation use efficiency in relation to ΔTEW is very low compared with that of *RF* is expressed by this equation very well. Namely, *IR* tends to be consumed not for ΔTEW but for *ET* and *P*. On the other hand, *RF* tends to work effectively for ΔTEW instead of *ET* and *P*, owing to the characteristics of these parameters. As *IR* is conveyed and distributed to the paddy fields gradually and constantly with a certain time lag, it is easily consumed by *ET* and *P* before contributing to the increment of *TEW*.

As *RF* is brought directly to the paddy fields without any time lag, it plays a significant role in the rapid increment of *TEW* during the presaturation period.

Though Eq. (8) does not include a time factor, it can be applied as a convenient method for the estimation of the presaturation requirement for a normal

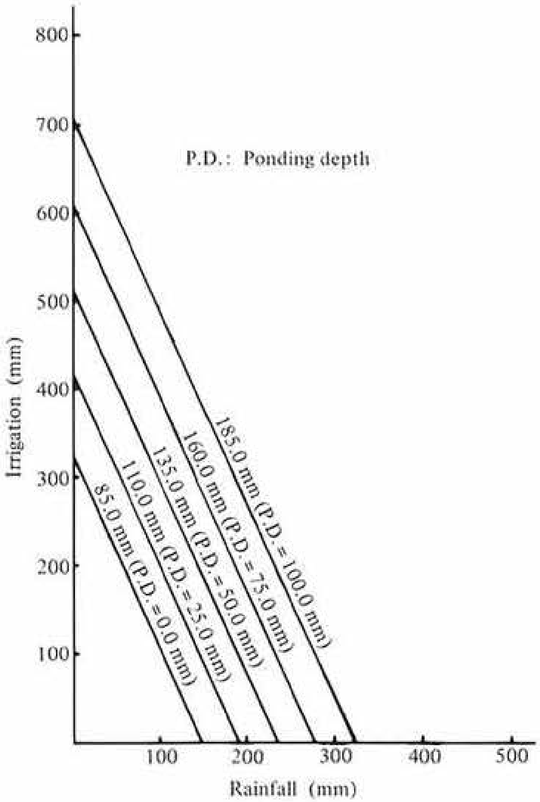

Fig. 4. Presaturation requirement for tertiary development area[2]

Table 2. Relative efficiency of *IR* against *RF* in relation to ΔTEW (*Epi/Epr*)

Item	ISA A, SCRBD5b, Muda Scheme, Malaysia		Taiwan, Japan
	Before tertiary	After tertiary	Consolidated
Canal density	10 m/ha	25 m/ha	100 m/ha
Water conveyance distance in paddy fields	1,650 m	445 m	100 m
Relative efficiency of *IR* against *RF* in relation to ΔTEW (*Epi/Epr*)	0.25	0.45 ($Epi=0.26$, $Epr=0.58$)	≒1.0 (presumption)

presaturation supply. Eq. (8) can be presented as shown in Fig. 4.

The relative efficiency of *IR* against *RF* in relation to ΔTEW (*Epi/Epr*) may be interpreted as an index of the water distribution speed in flat paddy lands. Based on Eq. (8), the value of *Epi/Epr* was 45% in the study area. According to the previous data obtained before the tertiary development[6], the value of *Epi/Epr* was calculated to be only 25%. Thus the increment of relative efficiency can be ascribed to the effect of tertiary development (Table 2).

(2) Paddy growth stage in the first season crop

In order to determine the irrigation and rainfall use efficiency during the paddy growth stage in the first season crop, monthly data were used for the analysis based on Eq. (2). It is very difficult to represent the irrigation and rainfall use efficiency by a linear equation, because heavy rainfall, which does not contribute linearly to the increment of effectively used water (*EUW*) in paddy fields, is very common during this stage compared with the presaturation period. Therefore, to overcome this difficulty, the upper limit of monthly effective rainfall was examined. At first, out of 8 sets of data, 5 sets for which the monthly rainfall was not very high were selected for the analysis. Then *Efi* and *Efr* were evaluated by the method of least squares. Based on the value of *Efi* and *Efr*, the upper limit of effective rainfall which gave a good agreement with the actual value of effectively used water was obtained. Finally, the following relationship was derived from the observed data on a monthly basis:

$$0.46 \cdot IR + 0.69 \cdot RF = \Delta TEW + ET + P \quad \ldots\ldots (10)$$

By assigning the value of *Efi* and *Efr* to the eight sets of data and comparing the actual value of *EUW* and the estimated one, it was found that Eq. (10)

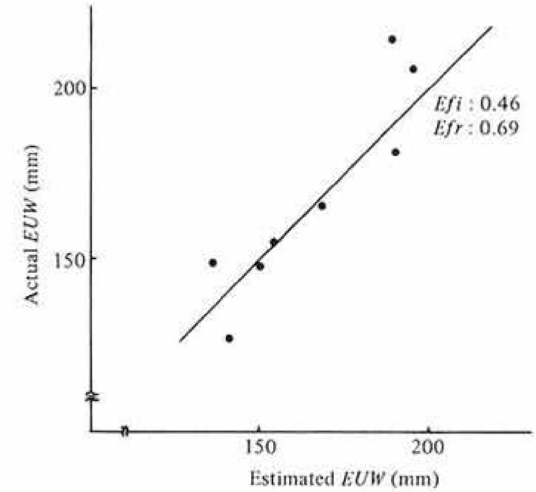

Fig. 5. Relationship between actual *EUW* and estimated *EUW*[2)]

needed the following modifications.

(a) When monthly *IR* is less than or equal to 40 mm, *Efi* is 1.0. When monthly *IR* is larger than 40 mm and less than 88 mm, $Efi \cdot IR$ is 40 mm.

(b) The maximum value of $Efr \cdot RF$ is 150 mm — that is, when monthly *RF* exceeds 218 mm, the effective rainfall is 150 mm.

Under the above-mentioned conditions, the relationship between actual *EUW* and estimated *EUW* is shown in Fig. 5.

Namely, *Efi* and *Efr* can be presented as follows:

$$\begin{aligned} Efi &= 0.46 && (\text{when } IR \leq 88) \\ &= 0.46 \sim 1.0 && (Efi \cdot IR = 40, \text{ when } 40 < IR < 88) \\ &= 1.0 && (\text{when } IR \leq 40) \quad \ldots\ldots\ldots (11) \\ Efr &= 0.69 && (\text{when } RF \leq 218) \\ &= 0.33 \sim 0.69 && (Efr \cdot RF = 150, \text{ when } 218 < RF < 450) \end{aligned}$$

References

1) Halcrow, W. & Partners, Consulting Engineer (1964): Report on reappraisal of the Muda River Project. London.
2) Kitamura, Y. (1988): Water balance in a tertiary development area with low and flat paddy land—case study in the Muda Irrigation Project area, Malaysia (I)—. *JSIDRE,* **13**, 18-35.
3) Muda Agricultural Development Authority (1977): Feasibility report on tertiary irrigation facilities for intensive agricultural development in the Muda Irrigation Scheme, Malaysia.
4) Soo, S. W. (1972): Semi-detailed soil survey of the Kedah/Perlis Coastal Plain.
5) Yashima, S. (1982): Water balance in low and flat paddy land—a case study in the Muda Irrigation Project area, Malaysia—. *JARQ,* **16**, 151-157.
6) Yashima, S. (1986): A study on water balance and development of field infrastructure for rice double cropping in the Muda area. *Nekken-shiryo,* **70** [In Japanese].

(Received for publication, Jan. 8, 1992)