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Evaluating Reference Crop Evapotranspiration of the Selected Field Crops Grown in Different Agricultural Regions in the Vietnamese Mekong Delta

Nguyen Dinh Giang Nam[1], Le Nhu Y.[1], Lam Van Thinh[1], Huynh Vuong Thu Minh[1], Pankaj Kumar[2] and Nguyen Vo Chau Ngan[1]*

[1]Department of Water Resources, Can Tho University, Can Tho City – 90000, Vietnam
[2]Institute for Global Environmental Strategies, Hayama – 240-0115, Japan
✉ nvcngan@ctu.edu.vn

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Abstract: The water balance in six selected crops (mung beans, tomatoes, maize, cassava, yam, and sweet potatoes) was determined at the field block scale in the Vietnamese Mekong Delta for two agricultural growing areas. A novel approach for the calculation of water balance was employed, which combined the reference crop evapotranspiration (ETo), derived from four methods, namely, Penman-Monteith, Blaney-Criddle, Thornthwaite, and Turc. The equation of Penman-Monteith is generally considered to be the most representative to calculate the ETo value. The reference crop evapotranspiration for some crops was calculated. The daily ETo ranges from 1.8 to 7.5 mm, while a monthly ETo ranges from 3.5 to 5.0 mm. The calculations of the water balances show that irrigation is necessary for crops grown on raised beds crops during the dry season. The results show a promising approach for evaluating the water regime to satisfy crop water requirements.

Keywords: ETo; Lowland fields; Raised beds; An Binh; Hoa An.

Introduction

Crop production is affected not only by farming practices, and soil profile, but also by geographical conditions and changes in meteorological patterns (Zhai and Zhuang, 2012). In temperate monsoon regions of the Vietnamese Mekong Delta (VMD), recent changes in climate have generally occurred by the increasing intensity of solar radiation, and air temperature (Elias et al., 2019). The temperature increased at all stations in the VMD over the year of 1981 to 2018, with an average trend of 0.76°C increase over 38 years (Trung et al., 2021). Extreme daily temperature also increased at all stations. Daily maximum temperature (Tx) had an average increase of 0.28°C per decade; while daily minimum temperature (Tn) also increased across the region, but the average increase of Tn was higher than that of Tx in the VMD (Trung et al., 2021). With higher air temperatures, evaporation rates are higher because as temperature increases, the amount of energy necessary for evaporation decreases. With the increasing trend of temperature in the VMD, more water loss by evaporation caused negative effects on agriculture production – the main income source for local residents in the region.

Evaporation is the process by which water precipitated in the ground's surface is released to the atmosphere by vapourisation, while transpiration is a process in which water vapour is released from parts of plants, especially through leaves and also through stems, flowers and roots

*Corresponding Author

(Karanth, 1978). The reference crop evapotranspiration (ETo) is used in the planning process for irrigation schemes as well as crop water requirements. The only factors affecting ETo are meteorological parameters. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development, and management practices (Allan et al., 1998). The potential crop evapotranspiration (ETc) is a key factor to determine the proper irrigation schedule and improving water use efficiency in irrigated agriculture. The ETc value can be estimated by an ETo value and the crop coefficient K_C (Doorenbos and Pruitt, 1975).

Evapotranspiration value can be obtained by many estimation methods such as Pan evaporation, Penman, Penman-Monteith, Thornthwaite, Jensen-Haise, Baier-Robertson, Turc, Priestly-Taylor, etc. (Mishra et al., 2021). Some of these methods need a number of weather parameters as inputs while others need fewer. Numerous methods have been developed for evapotranspiration estimation, out of which some techniques have been developed partly in response to the availability of data (Lee et al., 2004). In this study, formulas of Penman-Monteith, Blaney-Criddle, Thornthwaite, and Turc were applied for evapotranspiration calculation in the VMD.

Applying the insufficient meteorological and hydrological patterns for crop production caused negative water balance regime. By the current status in the VMD, the decrease in water availability for crop cultivation increases the need for efficient management of agricultural practice (Tuong and Bhuiyan, 1999). This study aimed to assess a water balance regime at a field block scale for selected crops according to soil water availability in specific agricultural growing areas in the VMD. To do so, a novel coupled approach was employed, which combined the Penman-Monteith method with the soil water balance. Further objectives were to compare the ETo values derived from various formulas of Penman-Monteith, Blaney-Criddle, Thornthwaite, and Turc.

Materials and Methods

Study Sites

The VMD covers an area of nearly 40,000 square kilometers with approximately 17.32 million of Vietnam's 97.58 million inhabitants living, in which about 75% of them in rural areas (Tuong and Bhuiyan, 1999). This region is the major food surplus area in Vietnam, providing more than 50% of the national agri-aquaculture productions. About 75% of the delta area is used for agricultural purposes, mainly in small-scale farming that limits advanced technique application. The main part of the fields is cultivated by paddy rice, fruits, which are common in the alluvial area, while other upland crops like mung beans, tomatoes, maize, cassava, yam, sweet potatoes, etc. are of next importance.

The experiments were carried out at two sites: An Binh ward from Can Tho city and Hoa An ward from Hau Giang province. These two sites were major representative of biophysical conditions of the VMD region (Figure 1). While the An Binh site is located in the suburban area with the alluvial soil type cover, the main crop is paddy rice, and the other crops are orchard and upland crops (Tuong and Bhuiyan, 1999); Hoa An site has mainly acid sulfate type of soil, where the main crop is paddy rice, and the other crops are upland crops (Tuong and Bhuiyan, 1999). Based on the crop cultivation at both An Binh and Hoa An sites, six crop types were chosen for the experiment including mung beans, tomatoes, maize, cassava, yam, and sweet potatoes as they are the most consumed plants in study areas.

At each site, three parallel field trials were established in both lowland fields and raised-beds. The raised-beds were newly constructed for the experiment. For this purpose, soil material was piled up with excavated soil from adjacent lowland areas to form ridges of 0.3 to 0.6 m height above the initial field surface. This procedure was based on farmer's experience and knowledge of the prevailing hydrological conditions.

Crop cultivation on these raised beds not only causes drainage of water but also the removal of soluble nutrients and toxic compounds (i.e., aluminum) from the root zone. The major task was calculated ETo, ETc, capillary rise (G_e), percolation (P) and finally the calculation of the soil water balance.

At An Binh site, Figure 2 shows the six groundwater level gauges on the raised-bed in the 1st farm (Wl, W2, W3, W4, W5, and W6) with the detailed cross-section (Figure 3) and the groundwater level gauge in the rice field (M1 with 43 cm depth) (Figure 4) were recorded at 8:00 AM. The three groundwater level gauges on raised-beds in the 2nd farm (W7, W8 and W9) and the 3rd farm (W10, W11 and W12) (Figure 2) were recorded at 8:00 AM, while the groundwater level gauges in rice fields of the 2nd farm (M2 with 33 cm depth) and the 3rd farm (M3 with 37 cm depth) (Figure 4) were recorded at 8:00 AM and 4:00 PM. The recorded water level data on the different gauges (Figure 2) in the raised-beds (W1-W12) and in the rice field (Ml-M3) were used for the calculation of the capillary rise.

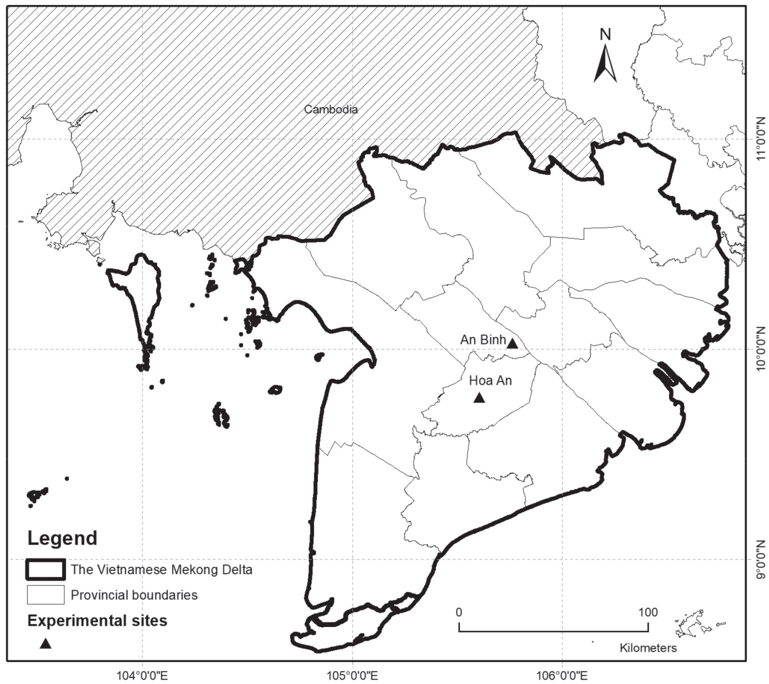

Figure 1: The experiment sites are in the VMD (An Binh ward - Can Tho city; Hoa An ward - Hau Giang province).

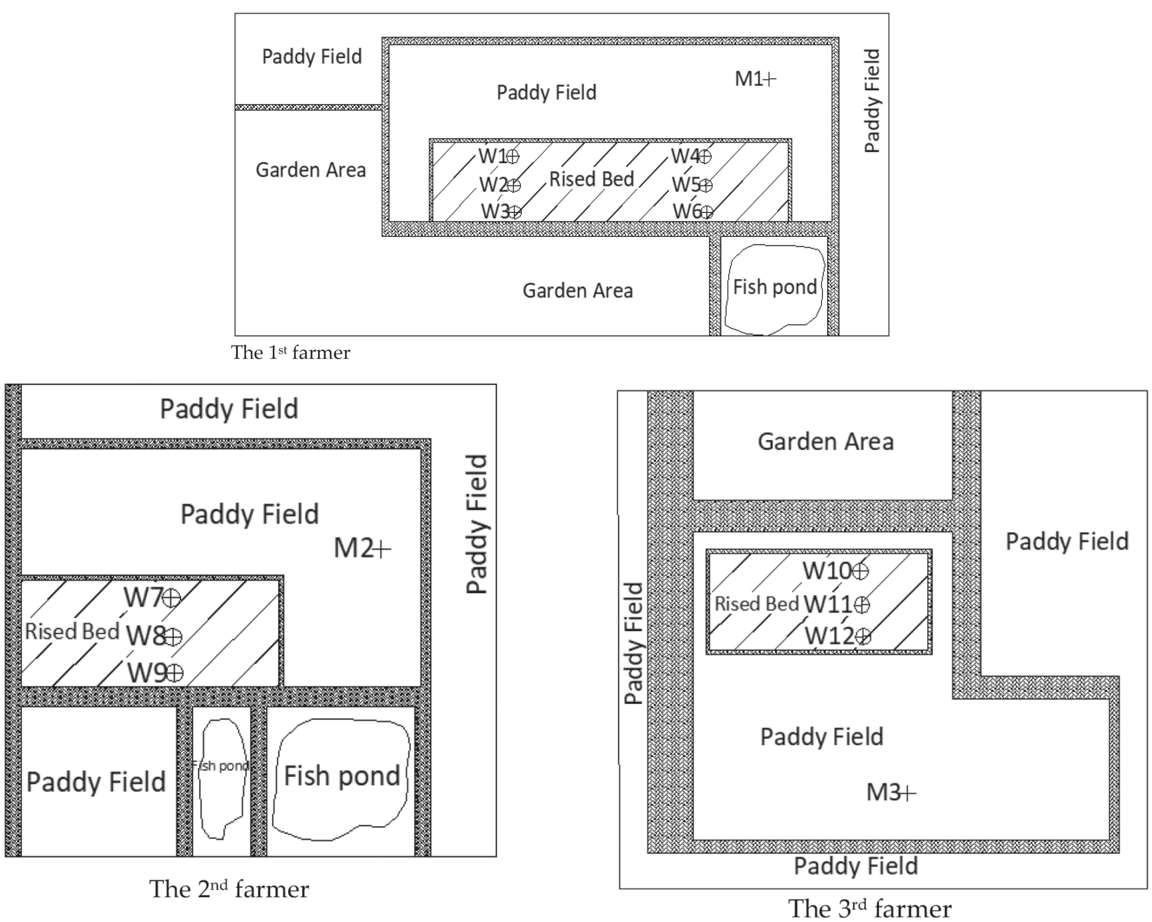

Figure 2: Schematic of the experimental field areas at An Binh site.

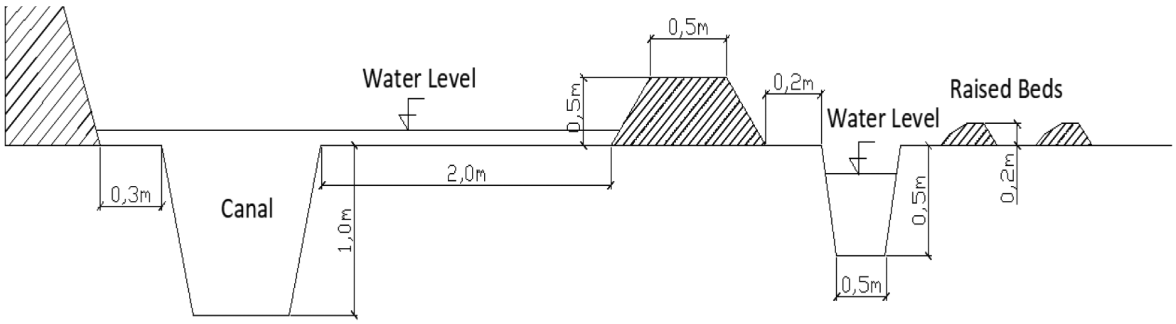

Figure 3: Detailed cross-section of raised-bed model applied in An Binh site.

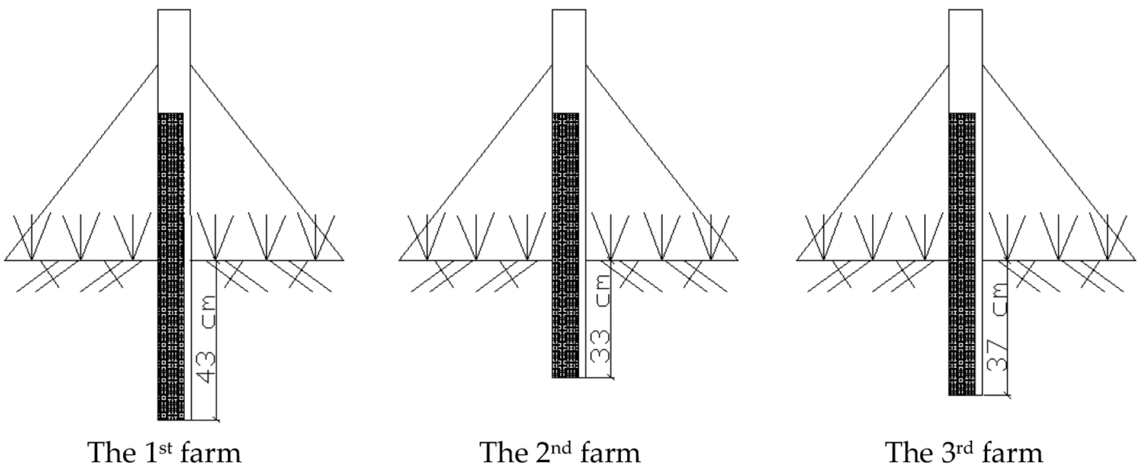

Figure 4: Groundwater level gauges in rice fields on the study farms at An Binh site.

Similarly, in the Hoa An site, the water level was recorded from three farmers' study fields at both raised-beds and rice fields at Hoa An site as described below:

- The 1st farmer: two observation holes on raised-bed (W1 and W2) were recorded at 8:00 AM and 4:00 PM; one water level meter in the rice field (M1) was recorded at 8:00 AM and 4:00 PM;
- The 2nd farmer: two observation holes on raised-bed (W3 and W4) were recorded at 8:00 AM and 4:00 PM; one water level meter in the rice field (M2) was recorded at 8:00 AM and 4:00 PM;
- The 3rd farmer: two observation holes on raised-bed (W5 and W6) were recorded at 8:00 AM and 4:00 PM; one water level meter in the rice field (M3) was recorded at 8:00 AM and 4:00 PM.

The calculated capillary rise appears small in comparison to the published data and may require field validation measurements.

Materials

For collecting the meteorological data from the study sites, climatic stations were installed at both the university campus at Can Tho city and the field site in Hau Giang province. The data collected in Can Tho represent the climatic situation of the adjacent experimental project area at An Binh (now called the Hoa An Binh site). The two measuring units (sensors, remote transmission and base station) were assembled and produced by the Adcon Telemetry company (Austria). Parameters such as relative humidity, precipitation, temperature, global radiation, wind speed and direction as well as soil temperature (at Hoa An site only) were digitally recorded at 15-minute intervals.

For the irrigation and drainage calculations of selected sites and field locations, the respective soil physical properties and the experimental specific crops were taken into account. For soil characterisation, three samples per location were taken from a depth of 10-20 cm, 40-50 cm and 80-90 cm, and analysed in the laboratory of Can Tho University (CTU).

Additionally, the computer simulation model, CropWat was used and tested for its practicability to optimise irrigation management and the calculation of effective rainfall. This calculation was based on methodologies by Smith (1992).

The capillary rise was calculated by the program of UpFlow (Raes and De Proost, 2003). The required input

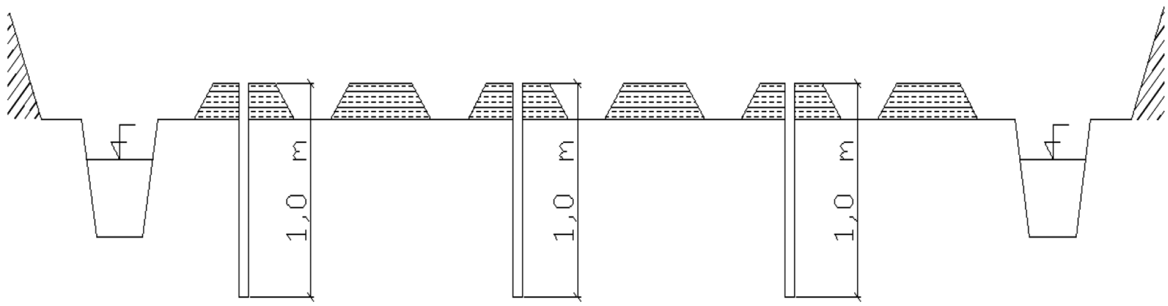

Figure 5: Groundwater level gauges in raised-beds.

parameters were selected based on soil characteristics and the groundwater level. Groundwater level gauges were installed on raised beds (shown in Figure 5).

Methods

The Reference Crop Evapotranspiration ETo

The ETo was calculated by the formulas of Penman-Monteith, Blaney-Criddle, Thornthwaite, and Turc. The results of the different calculation modes were comparatively evaluated.

- The Penman-Monteith equation (Allan et al., 1998)

$$\text{ETo} = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (1)$$

in which

R_n: net radiation (MJ.m^{-2}.day^{-1})
G: soil heat flux (MJ.m^{-2}.day^{-1})
γ: psychometric constant (kPa °C^{-1})
T: mean daily air temperature at 2 m height (°C)
u_2: wind speed at 2 m height (m.s^{-1})
e_s: saturation vapour pressure (kPa)
e_a: actual vapour pressure (kPa)
Δ: slope vapour pressure curve (kPa °C^{-1})

- The Blaney-Criddle equation (Blaney, 1962)

$$\text{ETo} = (a + b) \times [p \times (0.46 \times T_m + 8.13)] \quad (2)$$

$$a = 0.0043\ RH_{\min} - \frac{n}{N} - 1.41 \quad (3)$$

$$b = 1.21 + 0.545 U_m + 0.6\frac{n}{N} - \frac{RH_{\min}}{100} \quad (4)$$

in which

$RH_{\min}$: minimum monthly relative humidity (%)
n: sunshine duration per month (h)
N: astronomic possible sunshine duration (h)
U_m: wind speed (Beaufort)
p: mean daily percentage of total annual daytime hours for a given month and latitude
T_m: mean daily air temperature at 2 m height (°C)

- The Thornthwaite equation (Memorandum et al., 2000)

$$\text{ETo} = 0.533 \times f \times \left(\frac{10 \times T_m}{J}\right)^a \quad (5)$$

in which

f: correction factor obtained from given month and daylight hours (-)
T_m: mean daily air temperature at 2 m height (°C)
J: heat index (°)
a: exponent, depend on heat index (-)

- The Turc equation (Turc, 1961)

$$\text{ETo} = 0.4 \times \frac{T_m}{T_m + 15} \times (R_s + 50) + \frac{C}{30\ \text{days}} \quad (6)$$

in which

T_m: mean daily air temperature at 2 m height (°C)
R_s: global radiation (cal.cm^{-2}.day^{-1})
C: correction factor obtained from relative humidity ($C = 0$ if $RH > 50\%$)

The Potential Crop Evapotranspiration ETc

The upland crop-growing season has been divided into four stages: (i) initial stage; (ii) crop development stage; (iii) mid-season stage; (iv) late-season stage (Smith et al., 1992). For each stage and each crop type, crop coefficient (K_C) needs to be applied. The ETc values result from the multiplication of stage and crop-specific K_C values with the respective ETo as follows: $T_C = K_C \times$ ETo. Due to the small differences in ETc between the various crop plants, mung bean was used as a model crop for further computations.

Field Water Balance Calculation

The detailed analysis of the quantitative water use and the consumptive water use on the experimental fields were calculated with the following formula:

- The raised beds:

$$W_{i+1} = W_i + R + I + G_e - ETc - RO - P \quad (7)$$

- The rice field:

$$a_{i+1} = (a_i + I + R) - (ETc + P + S + D + RO) \quad (8)$$

where

W_{i+1}: soil water content in root zone at time i+1 (mm.day^{-1})

R: rainfall (mm.day^{-1})

I: irrigation (mm.day^{-1})

G_e: capillary rise (mm.day^{-1})

T_C: crop evapotranspiration (mm.day^{-1})

RO: run-off water (mm.day^{-1}) = 0 in dry season

P: percolation (mm.day^{-1}) = 0 if long time cultivated field

S: seepage (mm.day^{-1}) = 0 if long time cultivated field

D: drainage (mm.day^{-1}) = 0 in dry season

a_i: standing water at time i (mm.day^{-1})

a_{i+1}: standing water at lime i+1 (mm.day^{-1})

To calculate W_i, the value of the total available soil water should be known. This parameter was estimated from both soil analyses values and the UpFlow model. Also based on these secondary data, the field capacity was estimated at 180 mm/1,000 mm with an assumed available soil moisture of 80% of the field capacity. The water content in the root zone (w_r) was estimated to be:

$$w_r = \frac{180}{1000} \times 0.8 \times RZ \quad (9)$$

where RZ: the root zone

The different root zones were estimated based on the interpolation of the rooting depth between seeding and harvest of mung bean, tomato, maize and various tuber crops, and a mean value was applied for each crop. Table 1 shows the actual rooting depth variation and the actual mean value used for further calculations in An Binh.

Table 1: Rooting depths of different crops in An Binh

	Rooting depth (mm)	
	Variation	*Used for calculation*
Mung beans	150-250	200
Tomatoes	150-200	200
Maize	300-350	350
Tubers		250
• Cassava	300-350	
• Yam	200-250	
• Sweet potato	200-250	

Results and Discussions

Climate Changes

Tables 2 and 3 show that the climate data were collected from automated meteorological stations and analysed in view of providing climatic information relevant for the irrigation and drainage situations, especially during the dry season in the two study sites. Figure 6 shows the relation between temperature and rainfall during the year on a 10 years average for the Can Tho site, which is 1 m above sea level. The dry season, which was the primary focus of the field experiments, extends from December/January to April/May. Within 10 recorded years, the mean annual temperature value is 26.9^{o}C, the mean annual rainfall is 1,747 mm.

The study site of An Binh belongs to Can Tho city, while the Hoa An site is located in Hau Giang Province, Vietnam. They are located in a tropical monsoon climate belt. As a result, the rainy season is from May to November, the dry season is from December to April. The wind regime has two distinct seasons, the Northeast monsoon and the Southwest monsoon. At the An Binh site, the average annual temperature is about 28°C, the average number of sunny hours a year is about 2,249.2 hours, and the average annual rainfall reaches 2000 mm. The annual average humidity ranges from 82-87%. At

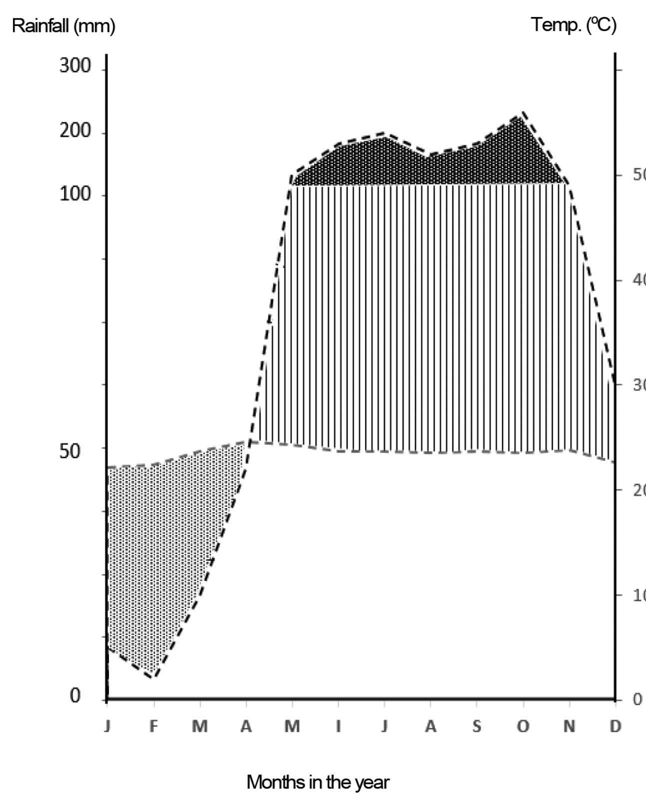

Figure 6: Climatic diagram of Can Tho.

Table 2: Measured climatological data in An Binh site

	Unit	*Time-line*							
		2019	*2020*						
		Dec	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*
T_{max}	ºC	32.0	30.4	30.9	33.1	35.5	33.8	32.5	33
T_{min}	ºC	20.3	22.9	19	18	24.9	24.9	24.2	23.7
T_{mean}	ºC	25.5	26	25.3	26.7	29.4	28.7	27.4	27
$RH_{\min}$	%	63	59	56	54	48	60	64	62
RH	%	79	77	76	73	72	78	81	87
R_{S1}	$W.m^{-2}$	176(1)	221(1)	199	212	233	207	174	171
R_S(2)	$MJ.m^{-2}.d^{-1}$	15.2	19.1	17.2	18.3	20.1	17.9	15	14.8
R_a	$MJ.m^{-2}.d^{-1}$	31.3	32	34.5	36.9	37.9	37.5	37	37.1
n(3)	$h.d^{-1}$	5.5	8	5.8	5.9	6.9	5.6	3.9	3.7
N	h	11.4	11.5	11.7	12	12.2	12.5	12.6	12.5
n/N	d^{-1}	0.5	0.7	0.5	0.5	0.6	0.5	0.3	0.3
Wind	$m.s^{-1}$	1.7	5.7	1.3	0.7	0.5	0.4	0.4	0.3
Rainfall	mm	0.8	21	0	20.8	10.4	133.4	115.8	219.4
ETo	$mm.d^{-1}$	3.5	5	3.8	3.9	4.5	3.9	3.3	3.2
Σ ETo	mm	108	155	110	122	134	120	98	101

Table 3: Measured climatological data in Hoa An site

	Unit	*Time-line*							
		2019	*2020*						
		Dec	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*
T_{max}	ºC	29.4	29.7	30.4	32.6	33.9	32.3	30.9	30.9
T_{min}	ºC	23.2	22.1	21.1	22.3	24.2	24.9	24.1	24.1
T_{mean}	ºC	26.3	25.4	25.1	26.9	28.2	27.9	27	26.7
$RH_{\min}$	%	63	64	62	55	57	71	77	77
RH	%	79	84	85	81	83	86	87	88
R_{S1}	$W.m^{-2}$	180(1)	193(1)	206	211	223	220	171	163
R_S(2)	$MJ.m^{-2}.d^{-1}$	15.6	16.7	17.8	18.2	19.3	19	14.8	14.1
R_a	$MJ.m^{-2}.d^{-1}$	31.2	32.1	34.6	36.9	37.8	37.4	36.9	37
n(3)	$h.d^{-1}$	5.7	6.2	6.2	5.8	6.3	6.4	3.8	3.3
N	h	11.4	11.5	11.7	12	12.2	12.5	12.6	12.5
n/N	d^{-1}	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.3
Wind	$m.s^{-1}$	0.1	0.2	0.2	0.2	0.2	0.3	0.4	0.4
Rainfall	mm	2	40.2	1.2	0	76.6	212	245	318
ETo	$mm.d^{-1}$	3.3	3.3	3.4	3.7	4.1	4	3.2	3.1
S ETo	mm	102	103	99	114	122	124	99	96

Notes:

(1) Calculation with $R_s = [0.25 + 0.5 \times (n/N)] \times R_a$ (10)

(2) $R_s = R_{s1} \times 0.0864$ (11)

(3) $n = [N \times (R_s/R_a - 0.25)/0.5]$ which was calculated with transformed of (10) (12)

the Hoa An site, the monthly maximum temperature is lower than An Binh while the minimum temperature is higher. The rainfall at the two sites is not quite different.

ETo-Calculation

Figures 7 and 8 show the comparison between the different ETo values calculated by the mentioned methods based on monthly means of ETo values for the period between December and July at An Binh and Hoa An sites, respectively.

Tables 7 and 8 show some differences. The Penman-Monteith formula is generally considered to be the most adequate. The results obtained using the Turc method are rather similar to the Penman-Monteith method and hence more appropriate than the highly variable data obtained with the Blaney-Criddle and the Thornthwaite methods. The program CropWat is based on the Penman-Monteith formula too, but it uses sunshine hours instead of global radiation (Smith et al., 1992). Table 4 shows the differences between the calculation methods.

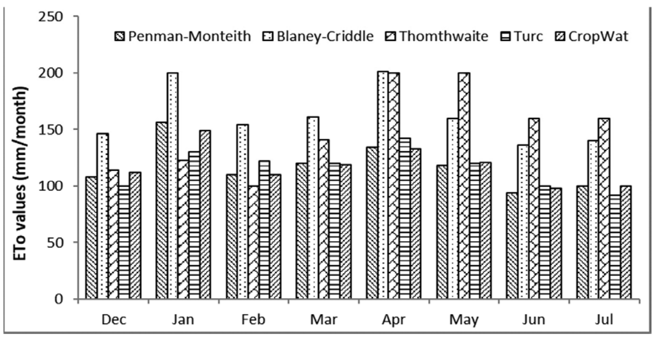

Figure 7: Comparison of different ETo calculation methods at An Binh site.

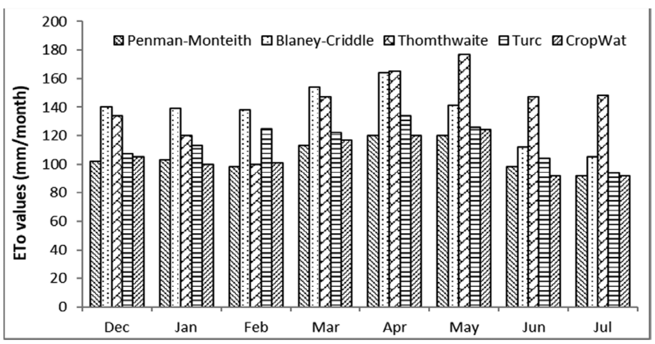

Figure 8: Comparison of different ETo calculation methods at Hoa An site.

Global radiation appears to have the largest influence on the ETo calculation in the area. Moreover, previous studies also reveal that global radiation has a direct influence on ETo values, and global radiation coupled with daily average temperature is the optimal combination for determining ETo (Petković et al., 2020). Although we found that the variation of other factors - wind speed, relative humidity, and temperature is relatively small, wind speed also has an effect on the accuracy of ETo estimation (Trajkovic and Gocic, 2021). Hence, besides the Penman-Monteith, only the Turc method of ET calculation (and, of course, the CropWat model) uses more than the order-classes of sunshine hours. In addition, small changes in global radiation have an effect.

The equation of Penman-Monteith is generally considered to be the most representative, as it includes all relevant components and provides the daily, decadal, and monthly potential ETo rates. Meanwhile, the Thornthwaite approach performs poorly regardless of wind speed (Trajkovic and Gocic, 2021). Consequently, the results of the Penman-Monteith formula were used for further computations.

Complete datasets from meteorological sensors to calculate ETc are available within the experiment period. Due to device and reading errors, the data record is not continuous and interpolations had to be used in some instances where data lags were only short-term. In the case of longer data deficits, monthly average values of the FAO station in Ho Chi Minh city were

Table 4: Parameters needed for the computations

Method	*Temperature*	*Relative humidity*	*Wind speed*	*Sunshine hours*[(1)]	*Global radiation*
Penman-Monteith	*	*	*	/	*
Bianey-Criddle	*	o	o	o	/
Thornthwaite	*	/	/	/	/
Turc	*	o	/	*	/
CropWat	*	*	*	*	(*)

Note: * - Measured data; o - Order-classes only; (*) - If available, but not essential

(1) If sunshine hours were not available, the formula (10) was used to convert global radiation into sunshine hours (12) (Allan et al., 1998).

used. Figure 9 shows the daily ETo values (based on the Penman-Monteith) calculated with the daily measured data in comparison with the average daily ETo values (based on the Penman-Monteith) on a monthly basis. The daily ETo ranges between 1.8 and 7.5 mm. On the daily average values calculated on monthly basis, ETo range between 3.5 and 5.0 mm. Figure 10 shows the comparison between 10 days' average ETo values (based on the Penman-Monteith) of An Binh and Hoa An sites. Values were calculated with daily measured data. The observed peak in January is the result of wind speed values up to ten times higher than in the remaining observation period.

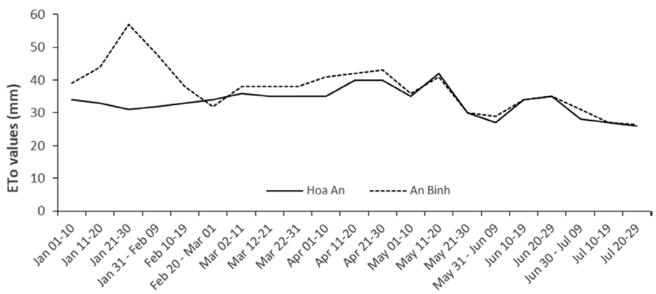

Figure 9: Daily ETo values (based on the Penman-Monteith) from An Binh site.

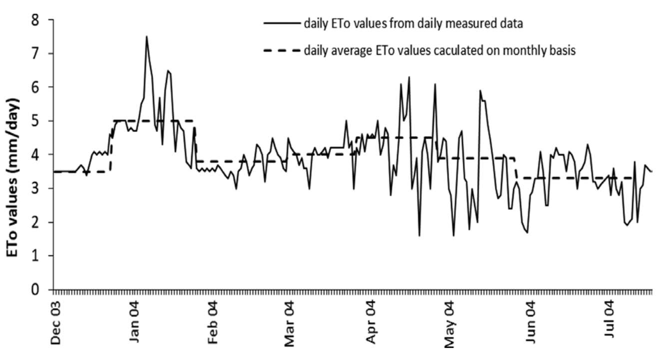

Figure 10: The 10-days ETo values from An Binh and Hoa An within experiment time-line.

To calculate ETc, the crop coefficient K_C value must be applied. The different values for An Binh and Hoa An result from differences in crop growth duration and crop phenology between the two sites, with a generally shorter growing period at Hoa An than at An Binh.

Table 5 shows the trend of K_C for the crops during the growing season in the An Binh site. In general, the averages of K_C in all crops had increasing trends during the growing season, from the initial stage to the harvest stage. However, low values of ETo at the end of January and the beginning of February in the crops could result in high values of K_C. The average of K_C in the crops initiated to increase from the crop growth stage to the mid-season stage reached the peak around the mid of the growing season and, the minimum was observed in the initial stage.

Table 6 shows the trend of K_C for the crops during the growing season in the Hoa An site. It reveals that the trend of K_C is similar to An Binh site crops. However, the K_C values of crops in Hoa An is lower in comparison with An Binh because they were impacted by acid sulfate soil condition.

Effective Rainfall

The effective rainfall (R_{eff}) was calculated using the program CropWat (FAO, 1993). This program is based on the USDA Soil Conservation Service Method. Table 8 shows the measured and effective rainfall.

Figure 11 shows the difference in effective rainfall at An Binh and Hoa An. The values are monthly amounts of daily data. From December to the beginning of March for Hoa An, and to the middle of June for An Binh, the ETo was higher than the effective rainfall. So, in this time no leaching proceeded.

Table 5: The KC values and the corresponding days in the different stages for the crops used in the experiment at the An Binh site

Crop	*Crop development stages*								
	Initial		*Crop growth*		*Mid-season*		*Late season*		*At harvest*
	K_C	*Days*	K_C	*Days*	K_C	*Days*	K_C	*Days*	K_C
Mung bean	0.40	20	0.75	20	1.05	30	0.90	15	0.90
Maize	0.30	15	0.70	30	1.05	30	0.85	15	0.55
Cowpea	0.40	20	0.80	30	1.20	30	1.15	10	1.10
Tomato	0.50	15	0.75	25	1.15	35	0.85	35	0.60
Tubers	0.45	25	0.75	35	1.10	40	0.95	35	0.75
Soy bean	0.30	20	0.70	25	1	45	0.70	20	0.40
Cucumber	0.60	9	-	15	1	20	0.75	5	-

Table 6: The K_C values and the corresponding days in the different stages for the crops used in the experiment at the Hoa An site

Crop	*Crop development stages*								
	Initial		*Crop growth*		*Mid-season*		*Late season*		*At harvest*
	K_C	*Days*	K_C	*Days*	K_C	*Days*	K_C	*Days*	K_C
Mung bean	0.3	15	0.65	15	0.95	20	0.90	5	0.85
Maize	0.3	10	0.70	20	1.05	20	0.80	5	0.55
Cowpea	0.4	10	0.70	25	1.05	25	1.00	10	1.00
Tomato	0.4	10	0.70	20	1.05	30	0.80	30	0.60
Tubers	0.4	20	0.70	25	1.05	25	0.85	20	0.70
Soy bean	0.3	10	0.70	15	1.00	35	0.70	10	0.40
Cucumber	No harvest (to sensitive)								

Table 7: Sawing and harvest date for An Binh and Hoa An

Crop	*Sawing date*		*Harvest date*		*Total growing time (days)*	
	An Binh	*Hoa An*	*An Binh*	*Hoa An*	*An Binh*	*Hoa An*
Mung bean	Dec 23	Feb 04	Mar 16	Apr 01	85	57
Maize	Dec 23	Feb 04	Mar 22	Apr 01	91	57
Cowpea	Dec 23	Feb 04	Mar 22	Apr 15	91	71
Tomato	Dec 23	Feb 04	Apr 11	May 04	111	90
Tubers	Dec 23	Feb 04	May 04	May 04	134	90
Soy bean	Dec 23	Feb 04	Apr 13	Apr 14	113	70
Cucumber	Dec 23	Feb 04	Feb 10	No harvest	49	-

Table 8: Effective rainfall on both climatic stations

Time-line	*Climatic station at An Binh site*		*Climatic station in Hoa An site*	
	Rainfall	*Effective rainfall*	*Rainfall*	*Effective rainfall*
December	58.0	52.6	58.0	52.6
January	21	20.3	40.2	37.6
February	0.0	0.0	1.2	1.2
March	20.8	20.1	0.0	0.0
April	104.0	86.7	76.6	67.2
May	133.4	104.9	212.0	140.1
June	115.8	94.3	245.0	149.0
July	219.4	142.4	318.0	156.8

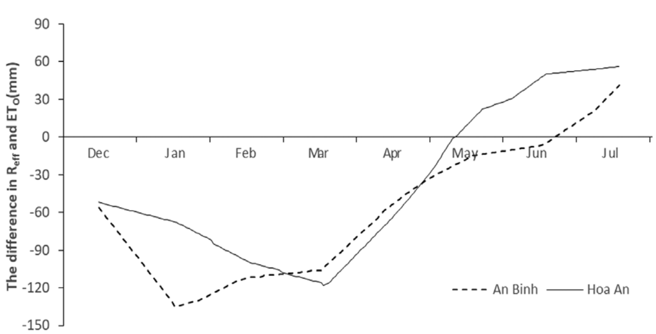

Figure 11: Comparison of the difference in R_{eff} and ETo from CTU and Hoa An.

Water Balance

The detailed computations of the water balances for raised beds show that the capillary rise does not cover the evapotranspiration losses. Hence, it is necessary to irrigate. At the initial growth stage, even daily irrigation may be required to foster root growth and crop development. There are substantial differences according to the different crops' types, the ETc and the respective root depths. In An Binh, the calculation of soil water balances of tomatoes and tuber plots become negative during the late season in spite of irrigation (4 mm the first 10 days, afterward 4 mm every second day). Crops with a total growing period of more than 90 days need to be irrigated either daily or with 6 mm water fall every second day during the late vegetative growth stages in the dry season. In Hoa An, no irrigation was necessary.

The calculation of the two sites (An Binh and Hoa An) results in different values because the harvest time at Hoa An was earlier than in An Binh in relation to the planting time. So, in Hoa An, the irrigation was sufficient. The longest total growing period in Hoa An site was 90 days (tomatoes and tubers).

Conclusions and Recommendations

The measurements show that on raised beds irrigation is necessary during the sunny season from December to May.

The calculation of evaporation should be estimated using the Penman-Monteith formula. It is important that the used formula calculates with measured global radiation or sunshine hours at least. We recommend the installation of a Class-A pan near the experimental fields to compare with climatologically calculated values.

For exact statements about the field water balance more onsite analyses are needed. For example, one should take more soil samples in specific vegetation periods to analyze the soil moisture at the time in different depths. Furthermore, it should be checked if in realty no runoff and no percolation in the raised beds occur.

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