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Evapotranspiration of Rice Fields in the Red River Delta

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Abstract

The present paper reports the results of several experimental studies on the evapotranspiration of rice for the Spring and October crops carried out during a five-year period (1972–1976) in the Red River Delta of Viet Nam. It was found that the evapotranspiration of rice depends highly upon the growth stages, the amount of fertilizer applied and climatological conditions. However, a linear relationship between rice evapotranspiration and each of the factors: pan evaporation, sunshine duration and atmospheric temperature was significant only for the Spring crop.

Introduction

The Red River Delta in the North with an area of about 70,000 hectares is the second largest rice bowl (after the Mekong Delta in the South) of Viet Nam. There are two major rice crops in this area, namely the *Spring crop* and the *October crop*. The first crop is grown between February and June, and the second crop is grown between July and October. In addition, there is the Winter crop of which the growing season is between these two major crops, i.e. between late October and the first half of February. However, this crop is grown only in the areas of the delta where water is available during that period.

The rice cultivation in this region faces many difficulties due to the irregularities of its climatological conditions. It has been observed that severe droughts, which usually take place during the first growth stage (in February or March), and heavy rains, which often fall in May or June, cause a lot of damages to the Spring crop. On the other hand, the October crop normally suffers from waterlogging and floods at the vegetative phase, and also from the shortage of water at the late reproductive phase. Therefore, one of the most appropriate ways to increase rice production in the region is to provide water supply appropriately and to improve the drainage capacity of the rice fields by means of irrigation and drainage systems. For these two purposes, the water consumptive use, also referred to as evapotranspiration (ET) must be accurately estimated. With the current introduction of high yielding, nitrogen responsive rice varieties, this estimation problem becomes even more important, because the success of rice cultivation now depends greatly upon the water supplied.

There have been several studies on the rice evapotranspiration in this delta. According to the data of HAI HUNG Rice Research Station provided by Giao [1969], the value of ET was largely affected by duration of plant

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growth, genetical characters and cultivation conditions. He reported that ET had the first peak appearing as early as 40 days before flowering and attained its maximum around 10 days before heading, and another peak at the milk stage. Khuong [1970] noted that a crop with a yield of about 3.5 t/ha consumed 457 mm of water in wet season and 530 mm in dry season with different rice varieties. The studies of Thanh [1974] and Tinh [1976] provided more information. It was found that for the Spring crop with a normal yield of 2.3 to 4.0 t/ha the total amount of ET ranged from 350 to 450 mm for the entire growing season. Moreover, the highest ET for the IR–8 variety was recorded at 6.8 mm/day at the heading stage, and when the normal nitrogen application (of 40 kg N/ha) was doubled, ET increased about 9%. For the October crop, the total amount of ET was in the range from 564 mm to 580 mm corresponding to a yield of 4.0 to 4.3 t/ha. More specifically, the highest value of ET for the IR–22 variety was recorded as 7.5 mm/day at the panicle initiation stage. When the normal nitrogen application was double, ET increased about 14%. However, there have been no attempts to investigate the problem of how the ET varies from season to season according to different growth stages and yields for the Red River Delta where climatological conditions fluctuate greatly. In the present study, this problem is investigated for the two major aforementioned rice crops. Moreover, the efficiency of water use at the different growth stages is also evaluated in terms of the grain yield.

Material and Method

The experiments were carried out for both the Spring and October crops, and for a five-year period, from 1972 through 1976. The experimental site was the field No. 4 of the University of Agriculture, Hanoi which is most representative of the whole delta and where adequate water supply could be ensured throughout the study periods.

The fertilizer application consisted of four levels as follows:

I Manure (5 t/ha)+N(60 kg/ha) +P(30 kg/ha)+K(30 kg/ha);

II Manure (10 t/ha)+N(120 kg/ha) +P(60 kg/ha)+K(60 kg/ha);

III Manure (15 t/ha)+N(180 kg/ha) +P(90 kg/ha)+K(90 kg/ha); and

IV Manure (20 t/ha)+N(240 kg/ha) +P(120 kg/ha)+K(120 kg/ha)

The water depth in all the plots was continuously maintained at 5 cm on a daily basis. For each fertilizer application, there were four square tanks, each having an area of 1 m^2 with cemented bottom.

The IR–8 variety was employed in the Spring crop and the IR–22 variety in the October crop because they have been widely cultivated in this region and are most likely to be so in the forthcoming years.

Daily readings of ET were made from these tanks by referring to the calibrated water depth stake with a nail placed at the zero level in each tank. After reading the ET at 7.00 a.m., water was added to maintain the 5 cm depth.

The climatological data at the nearby station (Lang, Hanoi) for the experimental

Table 1 Summary of Climatological Data for Experimental Period (1972–1976)

Climatological Factor		Spring Crop					October Crop				
		Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.
Mean Temperature, °C	(1)	15.4	17.8	22.3	26.8	28.3	28.2	26.9	26.7	24.1	29.8
	(2)	17.9	20.1	23.4	27.6	28.7	28.8	27.9	27.3	25.0	20.7
	(3)	20.7	22.2	24.9	28.5	29.0	29.3	29.0	27.7	25.7	21.6
Sunshine Duration, h	(1)	36.0	28.1	97.0	166.7	161.0	158.8	118.0	93.9	157.2	96.2
	(2)	59.4	47.3	105.2	204.7	181.1	189.1	159.1	179.9	172.3	134.7
	(3)	70.0	66.5	114.3	254.5	218.1	226.4	184.1	221.1	180.3	174.8
Rainfall, mm	(1)	8.2	22.1	78.1	166.7	128.4	166.3	190.2	173.0	86.4	15.0
	(2)	30.2	32.3	144.8	184.8	194.4	285.7	390.4	286.2	172.0	66.9
	(3)	68.8	53.1	286.9	219.9	273.4	492.0	756.7	472.0	272.8	139.2
Evaporation, mm	(1)	50.2	44.8	54.6	83.9	82.1	80.1	58.5	55.1	83.3	65.9
	(2)	53.0	27.3	63.0	90.2	95.6	89.8	77.9	80.6	96.0	88.6
	(3)	57.4	67.3	72.5	98.1	111.2	106.0	100.0	115.0	108.5	102.0
Relative Humidity, %	(1)	77.0	84.0	87.0	83.0	80.0	80.0	81.0	85.0	78.0	75.0
	(2)	84.4	86.8	87.0	84.0	83.0	82.8	85.2	85.8	80.8	80.0
	(3)	88.0	89.0	87.0	85.0	86.0	84.0	91.0	89.0	85.0	86.0

Notes: (1) Minimum value, (2) Mean value, (3) Maximum value

period are summarized in Table 1. These consist of the temperature (°C), sunshine duration (h), rainfall (mm), pan evaporation (mm), and relative humidity (%). In general, all these factors fluctuated greatly from *season* to *season* during the five years of experiments. However, their values in the same month for this five-year period did not vary very much, except for rainfall, as indicated by their minima, means and maxima.

Results

1. ET in Different Growth Stages

For the Spring crop, the experimental results shown in Table 2 indicate that the value of ET increased from the transplanting-tillering stage (A) to the heading-maturation stage (D), both in the percentage of the total amount and in the mean daily requirement. This implies that the maximum value of ET was attained at the last stage.

The mean daily value of ET also increased with the fertilizer amount employed, from level I through level IV in all the stages. In other words, when a larger amount of fertilizer is applied, a larger amount of ET is required accordingly. As shown in Table 2, the total amount (for the entire growing season) of ET increased from 508 mm for level I to 611 mm for level IV. However, for the percentage of the total amount of water employed in the various stages, there were two different patterns. A decreasing pattern was observed for stages A and D, and an increasing pattern was observed for the two middle stages —— viz. tillering-panicle initiation (B), and panicle initiation-heading (C) stages.

For the October crop, the value of ET was found to increase from stage A through stage C where it reached the maximum value in

Table 2 Evapotranspiration at Different Growth Stages (Average for Five Years)

Crop	Growth Stage	Level of Fertilizer Application							
		I		II		III		IV	
		% of total	mm/day	% of total	mm/day	% of total	mm/day	% of total	mm/day
Spring	A	11.0	1.94	10.9	2.05	10.6	2.10	10.2	2.20
	B	16.7	3.03	17.0	3.26	17.0	3.51	18.1	4.03
	C	28.7	4.75	29.3	5.20	30.8	5.43	31.2	6.27
	D	43.6	7.26	42.8	7.68	41.6	7.92	40.5	8.27
	total, mm		508		539		571		611
October	A	12.0	4.41	11.8	4.49	11.7	4.74	11.6	5.00
	B	27.6	4.86	27.6	5.12	27.9	5.47	27.6	5.74
	C	33.0	5.92	33.8	6.39	34.1	6.82	34.6	7.42
	D	27.4	4.86	26.7	4.89	26.2	5.18	26.2	5.50
	total, mm		552		581		615		653

Notes: A: transplanting-tillering, B: tillering-panicle initiation, C: panicle initiation-heading, D: heading-maturation
I: 5 tons of manure/ha + N (60 kg/ha) + P (30 kg/ha) + K (30 kg/ha), II: double dose, III: three fold dose, and IV: four fold dose

percentage as well as in the mean daily value. After this stage, ET decreased. This pattern was observed in all the levels of fertilizer applications.

Like the case of the Spring crop, the mean daily water requirement in any stage increased with the amount of fertilizer employed. Consequently, the total amount of water requirement increased significantly from 552 mm for level I to 653 mm for level IV.

2. *Relationship between ET and Climatological Data*

In this study, an attempt was made to find out possible linear relationships between ET and three climatological factors which are most commonly used in connection with the estimation of ET, namely the pan evaporation (EP), sunshine duration (SD), and atmospheric temperature (T). The values of ET and these factors observed during the four growth stages (A through D) throughout the experimental period (1972–1976) are shown in Tables 3 and 4 for the Spring and October crops, respectively.

i) ET and EP

For the Spring crop, while ET increased steadily from stage A through stage D, there was no such simple pattern for EP. However, a linear regression analysis applied to the values of ET and EP in Table 3 leads to the following equation:

$$ET = -2.12 + 2.90EP \qquad (1)$$

with the computed value of the correlation coefficient r equal to 0.839. This means that r^2 or 70% of the variation of ET is accounted for by eq. 1. With this percentage of the explained variation, eq. 1 may be acceptable. In fact, using an analysis of variance approach

Table 3 Values of ET, EP, SD and T for the Spring Crop

Growth Stage		1972	1973	1974	1975	1976
A	(1)	2.40	1.79	1.63	2.22	2.31
	(2)	2.33	1.70	1.90	1.87	2.29
	(3)	1.72	2.39	1.93	1.74	1.57
	(4)	19.30	18.00	17.70	18.60	18.90
B	(1)	3.55	3.14	3.81	3.50	3.40
	(2)	1.47	1.56	2.10	1.54	1.51
	(3)	2.94	2.35	2.90	1.18	2.13
	(4)	20.50	18.70	20.80	20.40	19.20
C	(1)	5.20	5.85	5.64	4.59	6.10
	(2)	2.75	2.84	2.80	1.94	2.70
	(3)	4.98	4.42	6.35	3.10	4.58
	(4)	26.00	26.80	26.00	23.80	26.40
D	(1)	8.00	7.70	8.30	2.90	7.22
	(2)	3.44	3.24	3.02	2.83	3.27
	(3)	6.86	6.90	6.64	5.44	5.68
	(4)	29.20	28.20	29.20	28.80	28.20

Notes: (1) ET in mm/day (obtained by taking the average of the values observed from four levels of fertilizer application), (2) EP in mm/day, (3) SD in h/day, (4) T in °C

Table 4 Values of ET, EP, SD and T for the October Crop

Growth Stage		1972	1973	1974	1975	1976
A	(1)	4.12	4.87	4.50	4.90	4.82
	(2)	2.80	2.81	3.10	4.01	3.24
	(3)	6.13	7.32	5.40	9.20	5.61
	(4)	27.60	29.10	28.30	29.30	29.30
B	(1)	5.24	5.40	5.20	5.70	4.75
	(2)	1.90	2.61	2.52	2.63	3.30
	(3)	4.20	5.61	5.01	5.90	6.40
	(4)	27.90	28.20	27.90	28.30	27.40
C	(1)	6.48	6.25	6.90	7.02	6.35
	(2)	2.72	1.80	2.50	2.50	3.70
	(3)	6.70	3.01	6.60	7.40	6.00
	(4)	27.00	26.80	27.50	27.60	26.90
D	(1)	5.61	4.95	5.12	5.40	4.75
	(2)	2.67	3.10	3.10	3.40	3.60
	(3)	4.90	5.20	5.40	5.60	5.50
	(4)	25.20	24.50	24.60	25.10	23.30

Notes: (1)–(4) same as in Table 3

[Walpole and Myers 1978: 296–297] the following statistic is obtained:

$F=42.761$ with 1 and 18 degrees of freedom

This statistic is much greater than the critical value at 5% level (4.41) as well as that at 1% level (8.29). Consequently, the relationship between ET and EP expressed in eq. 1 is significant.

For the October crop (Table 4), both the correlation coefficient and the F-statistic have very low values:

$$r=-0.375, \qquad F(1, 18)=2.950$$

therefore, a linear relationship between ET and EP should not be attempted.

ii) ET and SD

Both ET and sunshine duration data increased from stage A through stage D for the Spring crop (Table 3). Using a linear regression analysis, one obtains:

$$ET=0.65+1.06SD \tag{2}$$

with

$$r=0.921 \quad \text{and} \quad F(1, 18)=100.284$$

The high values for r and F indicate that eq. 2 is highly accepted.

However, for the October crop (Table 4), the computed values of r and F are very small:

$$r=0.031, \qquad F(1, 18)=0.017$$

Consequently, no linear relationship between ET and sunshine duration should be expected.

iii) ET and T

Like the case of ET and SD, the values of ET and T for the Spring crop (Table 3) increased from stage A to stage D. In this case, one obtains:

$$ET=-7.04+0.51T \tag{3}$$

with

$r=0.979$ and $F(1, 18)=410.842$

The extremely high values for r and F show that the linear relationship expressed by eq. 3 is highly significant. The coefficient of T in eq. 3 is positive indicating that ET increases with the atmospheric temperature. This fact has been observed by many researchers [Blaney and Criddle 1950; Lowry and Johnson 1942; Turc 1961].

On the contrary, the computed values of r and F based upon the data in Table 4 for the October crop are very low:

$r=-0.027$ and $F(1, 18)=0.013$

Hence one should not expect any linear relationship to exist between ET and T for this crop.

3. *ET and Yield*

The amount of water requirement and the grain yield (GY) are collected in Table 5. It is clear that when more fertilizer is applied, the values of the yield and ET are larger. Consequently, as the yield increases, ET increases as well. However, since the grain yield is so variable both in space and in time, and depends upon so many factors, it is impossible to predict ET simply from GY.

The results in Table 5 merely indicate that when one wants to increase the yield by applying more fertilizer, one should be prepared to provide more water accordingly.

4. *Water Use Efficiency*

The water use efficiency can be expressed by the grain yield (GY) obtained from a unit volume of water applied. The average values over the experimental period (1972–1976) are presented in Table 6.

For the Spring crop, the water use has the lowest efficiency during the transplanting-tillering stage (A), and the highest efficiency during the panicle initiation-heading stage (C) in all levels of fertilizer application.

For the October crop, the highest efficiency is still found in stage C, but the lowest efficiency is now in the heading-maturation

Table 6 Water Use Efficiency (kg/m³)

Crop	Growth Stage	Level of Fertilizer Application			
		I	II	III	IV
Spring	A	0.40	0.50	0.55	0.64
	B	2.61	3.17	3.95	3.95
	C	4.08	4.39	4.74	5.10
	D	1.02	0.89	0.93	0.98
October	A	0.89	0.87	0.89	0.94
	B	1.63	1.95	2.25	2.44
	C	2.88	3.32	3.29	3.52
	D	0.59	0.66	0.68	0.69

Table 5 Average Values of ET and Grain Yield (GY) over Five Years

Crop	Level of Fertilizer Application							
	I		II		III		IV	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Spring	508	5.57	539	6.32	571	7.72	611	8.78
October	552	4.60	581	5.39	615	6.06	653	6.90

Notes: (1) ET in mm, (2) GY in t/ha

Table 7 Accumulated Dry Matter of Rice Plant at Different Growth Stages (Average for Five Years)

Crop	Growth Stage	Level of Fertilizer Application I % of total	I kg/ha per day	II % of total	II kg/ha per day	III % of total	III kg/ha per day	IV % of total	IV kg/ha per day
Spring	A	2.2	9.0	2.7	11.0	2.3	13.0	2.8	19.0
	B	20.6	84.0	22.9	110.0	26.1	152.0	26.2	182.0
	C	54.2	197.0	54.2	228.0	54.5	285.0	54.3	364.0
	D	23.0	91.0	20.2	77.0	17.1	89.0	16.7	119.0
October	A	5.9	37.0	5.4	41.0	5.2	44.0	5.1	49.0
	B	27.6	82.0	28.5	101.0	30.4	125.0	31.1	142.0
	C	56.7	173.0	56.8	204.0	55.0	226.0	55.5	280.0
	D	9.7	29.0	9.3	35.0	9.4	35.0	8.3	39.0

stage (D).

The data in Table 6 also show that except for stage A, the water use in the Spring crop has a higher efficiency than that in the October crop. When compared with the accumulated dry matter data (Table 7), it can be said that both the Spring and October crops utilized water most efficiently when they accumulated the most amount of dry matter (i.e. in the panicle initiation-heading stage C).

Discussions

The evapotranspiration of rice in the Red River Delta was found to depend upon its growth stages, the amount of fertilizer applied (hence, its yield), and climatological factors.

1. For the Spring crop, the values of ET can be obtained from the pan evaporation data by using eq. 1; or from the sunshine duration data by making use of eq. 2, or from the daily atmospheric temperature data by using eq. 3. In the above equations, the coefficient of the linear term is always positive; consequently, ET increases with an increase in any of the factors EP, SD and T.

2. For the October crop, although significant linear relationships between ET and each of the factors EP, SD and T could not be established on the basis of the experimental data obtained, the relatively low differences between the values of ET during the four growth stages may be due a combined effect of these factors.

3. The results obtained in this study clearly show that ET is an increasing function of the grain yield. Even though one cannot expect to predict the evapotranspiration of rice from its yield —— a variable sensitive to many factors, one should be prepared to provide more water in return for a higher yield.

4. The equations obtained by means of the simple linear regression analysis were intended to provide estimated values of ET from each of the factors EP, SD and T. When data on all these factors are available, a relationship between ET and all these factors should be attempted because such a relationship would

be more meaningful for future estimates.

5. For the Spring crop, a multiple linear regression analysis gives

$$ET = -2.505 - 0.031EP + 0.494SD + 0.222T \quad (4)$$

with the following values for the determination coefficient R^2, and the F-statistic:

$$R^2 = 0.778, \quad F(3, 16) = 18.652$$

The linear equation obtained is accepted (even at the 1% significance level) and about 78% of the variation of ET is accounted for by eq. 4. However, a more detailed analysis of the results shows that the regression coefficients so obtained are not significantly different from zero by use of a suitable statistical test (F- or T-test). This means that a "better" linear model is possible. To see the specific contribution of each variable, a stepwise regression analysis [Draper and Smith 1966: 163–195] was carried out. It shows that only two variables are included as follows:

$$ET = -2.507 + 0.491SD + 0.219T \quad (5)$$

with $R^2 = 0.778$ and $F(2, 17) = 29.723$

The variable EP (pan evaporation) was not included due to its low contribution to the variation of ET [Nie *et al.* 1975: 320–367]. This is evidenced by the fact that the value of R^2 is almost the same after EP has been removed.

6. The same precedure was applied to the data for the October crop, but no linear equations were found to be meaningful.

In order to provide a way for estimating ET from EP, SD and T, an attempt was made to express ET as a polynomial of degree ≤ 2 in these variables. Fortunately, a stepwise regression analysis gives the following equation:

$$ET = 49.176 - 33.439EP + 3.288SD + 3.423EP^2 - 0.051T^2 - 1.407EP*SD + 0.039SD*T + 0.760EP*T \quad (6)$$

with $R^2 = 0.712$ and $F(7, 12) = 4.239$

This value of F indicates that eq. 6 is meaningful at the 5% significance level ($F_{0.05}(7, 12) = 2.91$) and the value of R^2 shows that about 71% of the variation of ET has been explained by eq. 6. Of course, while more efforts should be made to find out reasons for explaining why linear equations did not exist between ET and EP, SD and T, eq. 6 may be temporarily used for estimating ET in the October crop.

Summary and Conclusions

The experimental results on evapotranspiration of rice in the Red River Delta of Vietnam can be summarized as follows:

1. ET was affected by the fluctuations of climatological conditions from year to year as well as the growth stages under different levels of fertilizer applications. The dependence of ET on pan evaporation, sunshine duration, and atmospheric temperature can be expressed explicitly by simple linear relationships for the Spring crop.

2. The values of ET for the Spring crop on the four fertilizer application levels I–IV were 508, 539, 571 and 611 mm, respectively, and were distributed over the four successive growth stages as follows: transplanting-tillering: 10.2–11.0%, tillering-panicle initiation: 16.7–18.1%, panicle initiation-heading: 28.7–31.2%, and heading-maturation: 40.5–43.6%

of the total. For the October crop, the corresponding values were 552, 581, 615 and 653 mm with respect to the fertilizer levels and 11.6–12.0%, 27.6–27.9%, 33.0–34.6% and 26.2–27.4% with respect to the stages.

3. The mean daily values of ET corresponding to the four growth stages were 1.94–2.20, 3.03–4.03, 4.75–6.27 and 7.26–8.27 mm/day for the Spring crop, and 4.41–5.00, 4.86–5.74, 5.92–7.42 and 4.86–5.50 mm/day for the October crop, respectively.

4. The growth stage in which highest dry matter was accumulated was also the stage of maximum water use efficiency (panicle initiation-heading stage).

5. From fertilizer level I to fertilizer level IV when average grain yield increased from 5.57 to 8.78 t/ha for the Spring crop, and from 4.60 to 6.90 t/ha for the October crop, the average increase of ET was from 18.2 to 20.0% for both crops.

6. For the Spring crop, the values of ET can be estimated from eq. 1, eq. 2 or eq. 3 depending on whether data are available for EP, SD or T, respectively. Even when data are available for all these variables, ET should be computed from eq. 5 rather than from eq. 4.

7. For the October crop, one may use eq. 6 for estimating ET from data on all the variables EP, SD and T. No simpler expressions were found in this case.

More attempts will be made to investigate the evapotranspiration of rice during the October crop in the Red River Delta. A daily basis will be used in the search for relationships between ET and EP, SD, and T during each growth stage, and related results will be reported. If such attempts fail to produce any significant results, a further experiment with an elaborate design will be carried out.

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