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Seasonal weather effects on crop evapotranspiration and rice yield

(Kesan perubahan musim terhadap penyejatpeluhan tanaman dan hasil padi)

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Key words: evapotranspiration, crop establishment systems, seasonal yield, direct seeding, transplanting, crop productivity

Abstrak

Kajian keperluan air tanaman pada musim yang berlainan, kadar benih dan juga perbandingan kaedah anggaran keperluan air dengan penentuan pada peringkat ladang menunjukkan tiada hubungan yang nyata antara kadar benih dengan penyejatpeluhan (ET). Kadar benih yang rendah akan diganti dengan lebih banyak anak padi selepas pokok mula membesar. Nilai purata nisbah ET/Epan ialah 1.56 sepanjang pertumbuhan tanaman pada musim utama dan 1.75 pada luar musim. Terdapat perbezaan dalam nilai ET antara pelbagai varieti padi dan perbezaan ini lebih ketara antara musim. Nilai ET lebih tinggi bagi tanaman luar musim. Kaedah anggaran, Jensen-Haise dan Hargreaves Radiation, tidak dapat memberi banyak faedah untuk mendapat ET yang tepat, begitu juga dengan model simulasi Cropwat 7.0. Biasanya hasil padi lebih rendah pada luar musim dan juga pada tanaman padi secara mencedung. Sistem penanaman secara tabur terus dapat memberi hasil yang lebih tinggi daripada penanaman secara mencedung pada musim utama.

Abstract

Studies on the crop water requirement over different seasons, seeding rates and the comparison of estimation methods against field measurement showed that there is no significant effect of seeding rate on evapotranspiration (ET). Lower seeding rates were compensated upon crop establishment with more tillers. The average value of ET/Epan ratio was 1.56 throughout crop growth in the main season and 1.75 during the off-season. The ET value differed between rice varieties and was distinctly higher in the off-season. Estimation methods such as Jensen-Haise and Hargreaves Radiation are not quite useful for reliable measurement of actual field ET and neither is the simulation model Cropwat 7.0. The yield of direct seeded crop is generally lower in the off-season, so is the transplanted crop. Crop establishment by direct seeding is more productive than by transplanting in the main season.

Introduction

In designing any rice irrigation project, it is important to understand water requirement for rice cultivation under varying field conditions and factors affecting these situations respectively. Crop water requirement is referred to as the sum total of evaporation from rice field, crop transpiration, seepage and percolation losses during the growth period. Evapotranspiration

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(ET) describes the combined values of evaporation (E) and transpiration (T) from a specific planted area. The pan evaporation (Epan) refers to evaporation from a U.S. Class-A pan.

Studies on ET of rice were extensively conducted during the 70s particularly on wetland transplanted rice. Such research in Malaysia began in the 60s (Sugimoto 1971). Rice varieties studied then were Ria, Bahagia and Radin Ebos 33. Results showed that ET/Epan ratio were 1.0 to 1.2 during the early growth stage, 1.2 to 1.3 during the maximum tiller number stage and 1.4 during the heading stage with the ratio averaging at 1.2 throughout the growth period. The ET values ranged from 527 to 1 255 mm per season. During the same period, similar results were obtained from other studies, which reported that the ET/Epan ratio also ranged from 1.2 to 1.3 (Sugimoto 1971). Besides, differences in ET values if any, between the tropics and temperate areas and between seasons had not been significant as well (Iwakiri 1965; Hatta 1967; Kuang et al. 1967; Kotter 1968; Vamadevan and Dastane 1968).

Subsequent research on water requirement then became more inclined towards a blanket approach study, often on a water balance plot or block basis to compare water requirement by transplanted and direct seeded rice in the study of ET, presaturation, percolation and seepage losses for the growth period. Later, new varieties and different cultural practices (direct seeding) were introduced and adopted but very little work was conducted on the ET component separately.

Yashima (1984) in his study on the pattern of water requirement under transplanted and direct seeded rice in Muda reported that the ET/Epan ratio varied from 1.03 at the early growth stage to as high as 1.46 at the heading stage, with an average of 1.24 under direct seeding. In another investigation, Kitamura et al. (1984) reported that the seasonal ET value for transplanted rice in MADA added up to 778 mm from a daily equivalent of 10.6 mm. Later, Kitamura (1987) also reported that the seasonal ET values were 631 and 604 for the main-season and off-season crops, respectively. These ET values were calculated based on the documented ET/Epan ratio. Fujii and Cho (1996) revealed that the direct seeded crop consumed less water than transplanted crop based on the irrigation block studies. They reported that the supply of irrigation water between 1979–81 (transplanting was still dominant) had amounted to 1 836 mm on the average and between 1988–90 (direct seeding became dominant), supply then dropped to 1 333 mm throughout the entire season of crop growth.

Thus, two of the main influencing factors, new varieties and different crop establishment methods, each with discerning cultural practices, may possibly have affected crop water requirements. Irrigation water use between seasons varies considerably due to climatic influence on ET in the field resulting in different crop yields between seasons.

The purpose of this study is to determine the consumption of water in the rice field by measuring evaporation and transpiration during the growth of commonly planted rice varieties using current cultural practices. The results obtained would first be compared to pan evaporation, Jensen-Haise equation, Hargreaves Radiation method and simulation from Cropwat model version 7.0, and leading to a meaningful estimation of ET values in any standard year. Corresponding crop performance would also be monitored accordingly.

Materials and methods

Three sets of experiments were conducted to determine crop yield performance in general and detailed crop water requirement of rice under controlled as well as natural environmental conditions. The first set of experiments was conducted to evaluate crop water requirement under glasshouse condition whereas the second set was carried out in actual rice field environment. The third set was to evaluate crop yield. All the experiments were carried out at MARDI Seberang Perai research station from 1995 to 2000. The station is located at the longitude of 100.3° E, latitude of 5.39° N and elevation of 5 m above sea level. The air humidity is always above 80%.

Experiment 1

Plastic troughs, 60 cm x 38 cm and 15 cm high, were filled with rice soil to a depth of 10 cm. Rice variety MR 167 was row seeded in the trough at the rate of 50, 75, 100, 150 and 200 kg/ha. The soil was then wetted to field saturated condition to trigger germination. After a week, water would be topped up to 5 cm depth to maintain soil under flooded condition. ET readings were obtained by weighing the trough respectively twice or thrice a week depending on the growth stages. Depleted water would be replenished after each weighing. A randomized complete block design with three replicates was tested and repeated over three seasons. Ambient temperature in the glasshouse ranged from 22 °C to 41 °C throughout the duration of the experiment.

Experiment 2

Rice field of approximately 0.7 ha in size was used as the test plot. Aluminium tanks, 91 cm x 91 cm and 61 cm high, were installed for ET measurement. Different rice varieties were seeded in these ET tanks at the equivalent rate of 80 kg/ha. Another set of aluminium evaporation tanks (E tank) made up of two compartments and connected by a 5 cm diameter pipe were placed on the soil surface. The size of each compartment is 30 cm x 137 cm and 30 cm in height. These tanks were used to measure free evaporation from the water surface. Rice crop was planted around both E and ET tanks and neighbouring fields. Similarly, a randomized complete block design with three replicates was tested and repeated over four seasons.

The water level in both types of tank was measured in mm units twice a week in the morning with a Casella hook gauge. After measurements had been recorded, water would either be drained or supplied accordingly to maintain water level at 5–7 cm in depth. Readings obtained on days with heavy rainfall which caused overflow both in tanks and plot would be disregarded.

Meteorological observations of rainfall, pan evaporation, temperatures, sunshine hour and wind speed were recorded at the weather station located within the experimental farm.

Methods of estimating evapotranspiration

E and T values fluctuate according to changes in weather conditions, such as wind speed, air humidity, ambient temperature, sunshine hour and at various growth stages of a crop. To account for fluctuations due to weather conditions, the ratio of ET to pan evaporation (Epan), i.e. ET/Epan, is generally used. On the other hand, to estimate ET from climatic information, the crop coefficient (Kc) was introduced. Kc is expressed as the empirical ratio of the crop ET to some reference ET (to be derived from climatic data or pan evaporation) that have been obtained from experimental data according to the relationship:

$$Kc = \frac{ET\ (crop)}{ET\ (reference)}$$

where Kc is a dimensionless crop coefficient for a specific crop (either grass or alfalfa) at a given growth stage and soil moisture condition, and ET is daily crop ET.

This is a widely used approach in Western countries to estimate crop ET from the Kc values. However, for the purpose of this study, ET/Epan ratio is used throughout the discussion instead of ET/ET(ref) unless stated otherwise. As most of the research work on rice in this region expressed their findings in ET/Epan ratio, it is reasonable to use the formula in this paper.

Estimating crop ET using Jensen-Haise method

The Jensen-Haise method (Jensen and Haise 1963) is one of the procedures for estimating ET from climatic data. Input parameters required are elevation, long term mean temperature, solar radiation and air temperature. This method estimates an alfalfa reference crop evapotranspiration *(Etr)* as defined by Jensen et al. (1970). The method presented here is known as the 'Modified Jensen-Haise' method. The ASCE Irrigation Water Requirements Committee recommends that estimates using the Jensen-Haise method be made for periods of 5 days to a month.
The Jensen-Haise method is as follows:

$$Etr = C_T\,(T - T_x)\,R_s$$

where *Etr* has the same units as R_s and is compatible with alfalfa based crop coefficients

$$C_T = \frac{1}{C_1 + 7.3C_H}$$

$$C_H = \frac{50\text{ mb}}{e_2 - e_1}$$

$$C_1 = 38 - \frac{2E}{305}$$

$$T_x = -2.5 - 0.14(e_2 - e_1) - \frac{E}{550}$$

where e_2 is the saturation vapour pressure of water in millibar (mb) at the mean monthly maximum air temperature of the warmest month in the year (long term climatic data), e_1 is the saturation vapour pressure of water in mb at the mean monthly minimum air temperature of the warmest month in the year, and E is the site elevation in m.

For this study, the ET ratio for each week from sowing until harvesting were calculated. Similarly, the Kc values for each week throughout the growth period were established and compared.

Hargreaves radiation method

The Hargreaves radiation method was derived from eight years of studying grass lysimeter data at Davis, California (Hargreaves and Samani 1982, 1985). During this investigation, solar radiation data were frequently not available. Thus Hargreaves and Samani recommended that solar radiation be estimated from extraterrestrial radiation, R_A, and the difference between mean monthly maximum temperature and mean monthly minimum temperature, *TD*, in °C.
The equation is

$$Eto = 0.000939\, R_A TD^{1/2}\,(T + 17.8)$$

where *T* is the mean air temperature.

Since solar radiation is no longer a direct input parameter, the only variable for a given time period and location is air temperature. Therefore, this method has become a temperature-based method.

Cropwat – A computer program for irrigation planning and management

Cropwat is a decision support system developed by the Land and Water Development Division of Food and Agricultural Organization (FAO) of the United Nation, and the website is accessible to public via the FAO: Water Service. It can be used to calculate reference evapotranspiration; crop water and crop irrigation requirements. However, only Cropwat Version 7.0 is capable of calculating crop water requirement for rice which uses the FAO (1992) Penman-Monteith method for calculating crop water and irrigation requirements based on inputs of climatic and crop data.

Experiment 3

Within the same duration of eight consecutive crops over four main seasons and four off-seasons as the earlier two studies, a third experiment was carried out on a split-plot design to observe seasonal crop performance in terms of grain yield being affected by systems of crop establishment, these in turn being influenced by prevalent water situation in the field. With the main season and off-season as main plot treatments, the subplot treatments were six systems of crop establishment like row-seeding every season, broadcast every season, main season broadcast followed by off-season transplant, main season transplant followed by off-season broadcast, transplant every season and intensive transplant every season to be tested in experimental field plots each measuring 4 m x 5 m replicated four times.

A rate of 100 kg/ha presoaked seeds of variety MR 123 was used for all direct seeded treatments, which were either row-sown 25 cm apart or broadcast freely. Two to three seedlings at 25 days old were transplanted per point distanced at 20 cm x 25 cm but for the intensive system, three to five younger seedlings at 15 days old were transplanted closer together at 18 cm x 23 cm. Most farm operations were manually done. Crop management was uniformly practised for all treatments throughout from establishment to harvesting. Harvest area of each treatment plot was 3 m x 4 m in size. Dried and cleaned grain yields were compared statistically.

Results and discussion

Effect of seeding rate on ET under glasshouse environment

The results of different seeding rates of 50, 75, 100, 150 and 200 kg/ha are shown in *Table 1*. Analysis of variance did not show any significant difference at 5% level when ET was compared. This could be due to the interactive effect of the E and T components especially where seeding rate was low, T values would also be low accordingly. This situation allowed more soil to be exposed to sunlight giving rise to higher E values, thus compensating each other for ET values to be stabilized. Conversely, higher T values would likely be compensated by lower E values.

ET and ET/Epan ratio under glasshouse condition

Results of ET and ET/Epan ratio obtained from different seasons are shown in *Table 2*. The ET and ET/Epan ratio were small during the early growth stage but they increased gradually with time. Both ET and ET/Epan ratio peaked around the maximum tillering stage then again upon heading. Lower values were registered between these two stages for the main season crop *(Figure 1)*. The earlier peak at active tillering was lower than the peak near harvesting while the off-season crop displayed a more typical bell shape ET curve. Both main season and off-season crops showed a sharp decline in value from the ripening stage onwards which was mainly due to senescence.

Table 1. Effect of seeding rate on seasonal evapotranspiration under glasshouse condition

Seeding rate* (kg/ha)	Evapotranspiration (ET) in mm			
	main season 95/96	off-season 96	main season 96/97	off-season 97
50	633.8	976.3	616.5	806.4
75	650.4	962.7	608.8	862.5
100	623.4	1109.0	680.6	1053.0
150	620.7	953.0	692.8	890.7
200	641.5	1102.3	669.5	961.8
Mean	634.0	1020.7	653.6	914.9
CV (%)	7.6	11.0	9.7	15.7

*Rice variety MR 167

Table 2. ET and ET/Epan ratio for rice variety MR 167

Days after seeding	Total ET				Total Epan				ET /Epan Ratio			
	MS 95/96	OS 96	MS 96/97	OS 97	MS 95/96	OS 96	MS 96/97	OS 97	MS 95/96	OS 96	MS 96/97	OS 97
1–7	16.1	14.9	14.0	19.4	25.3	42.5	27.6	33.2	0.64	0.35	0.51	0.58
8–14	22.9	18.3	16.1	17.8	27.2	33.8	25.6	33.1	0.84	0.54	0.63	0.47
15–21	23.6	34.9	21.0	37.8	28.7	40.6	26.2	44.3	0.82	0.86	0.80	0.85
22–28	22.8	42.5	23.7	42.7	29.4	32.0	24.5	34.9	0.78	1.33	0.97	0.88
29–35	35.6	43.0	34.4	55.6	24.0	28.1	26.5	30.4	1.48	1.53	1.30	1.83
36–42	41.9	39.7	51.0	64.0	26.8	31.0	32.5	31.7	1.56	1.28	1.57	2.02
43–49	34.0	69.0	45.9	66.0	18.5	31.8	23.3	28.0	1.84	2.17	1.97	2.36
50–56	45.7	77.7	57.0	83.6	22.9	30.8	27.1	35.8	2.00	2.52	2.10	2.34
57–63	51.6	60.4	59.3	76.0	28.4	22.8	22.8	29.4	1.82	2.65	2.60	2.59
64–70	77.0	88.9	51.1	65.8	34.4	29.9	24.2	23.5	2.24	2.97	2.11	2.80
71–77	75.8	100.2	49.1	69.6	35.8	30.5	29.4	29.7	2.12	3.29	1.67	2.34
78–84	62.8	73.9	67.6	70.3	23.7	22.1	27.1	34.0	2.65	3.34	2.49	2.07
85–91	87.0	89.9	52.7	67.7	38.5	37.2	21.1	35.4	2.26	2.42	2.50	1.72
92–98	47.3	91.9	54.7	56.1	40.9	29.4	26.7	29.5	1.16	3.13	2.05	1.64
99–105	14.7	80.4	44.7	56.5	25.5	36.7	26.4	33.4	0.58	2.19	1.69	1.69
106–112	ND	54.6	14.8	32.5	ND	23.2	25.5	21.6	ND	2.35	0.58	1.50
113–119	ND	39.8	ND	26.7	ND	34.5	ND	32.6	ND	1.15	ND	0.82
Seasonal Total	658.8	1 020.0	657.1	908.1	430.0	536.9	416.5	540.5				
Seasonal Avg./day	6.3	8.6	5.9	7.6	4.1	4.5	3.7	4.5	1.53	1.90	1.58	1.60

Date of seeding: 5 Oct 95 (MS 95/96); 18 Mar 96 (OS 96); 15 Aug 96 (MS 96/97); 3 Apr 97 (OS 97)
MS = main season, OS = off-season, ND = no data

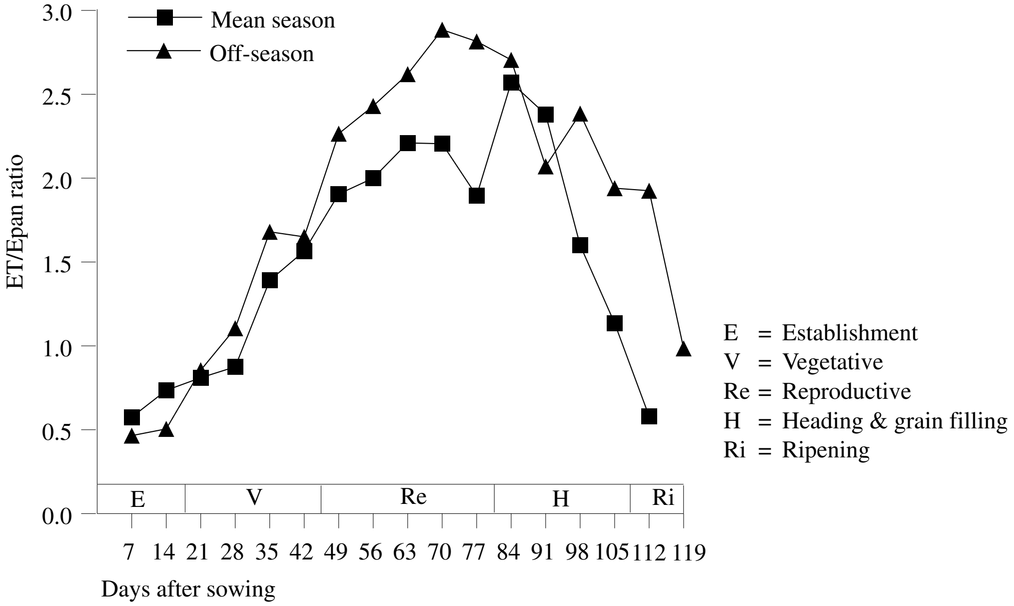


Figure 1. ET/Epan ratio at different stages of growth under glasshouse condition from main season 95/96 to off-season 97

The average value of ET/Epan ratio was 1.56 for the main season crop, ranging from 0.5 during the early stage of growth, 2.2 during maximum tillering to 2.6 at the heading stage. For the off-season crop, the average was 1.75 with the ET/Epan ratio peaking at 2.8 just after the heading stage. The average seasonal ET were 658 mm and 964 mm for the main season and off-season crop, while the average daily ET were 6.1 mm and 8.1 mm respectively.

During the early stage, the ET/Epan ratio was lower when compared with the results obtained in Muda Agricultural Development Authority (MADA) by Sugimoto (1971). This difference may be due to the dry direct seeding being practised now against what had usually been wet transplanting then. During the first week after sowing, soil in the troughs was maintained at field saturation to trigger germination. Field saturated condition at this time could minimize evaporation from the soil surface. The higher ET/Epan ratio at mid-season may have been caused by the advective energy brought by winds from drier areas (De Datta et al. 1970).

Comparing seasonal values of the four cropping seasons *(Table 2)*, the average seasonal ET values were higher in the off-season than in the main season. The same trend was also evident in the comparison between the average daily ET values (irrespective of maturation period), whereby the off-seasons' values were consistently higher than the main seasons'. This is due to the weather effects where the off-season is normally drier with higher day temperature and longer sunshine hours as compared to the main season.

Comparison of ET and ET/Epan ratio under glasshouse and field environment

Rice variety, MR 167, was seeded simultaneously in the glasshouse and open field during the off-season 1997. Then, MR 185 was grown in the following season, 97/98 main season, but only in the field. The intention was to evaluate and compare values of the ET/Epan ratio where rice was grown under two different environments.

Results showed that the curve pattern of ET and ET/Epan ratio from field test were similar to those in the glasshouse. The two familiar distinct peaks in the ET curve of the main season crop as well as the typical ET curve appeared during the off-season were similar in both situations *(Figure 2).*

Compared to an average value of 1.60 under glasshouse condition, field reading of ET/Epan ratio was at 1.29. The lower value during the same growth period could be due to the growth environment of the field plots which were surrounded by irrigated rice fields unlike the isolated drier environment in the glasshouse.

Comparison of ET between rice varieties over different seasons

The results obtained for each variety during the different seasons are shown in *Table 3* and *Table 4*. Analysis of variance on each variety is summarized in *Table 5*. Every rice variety exhibited a similar ET trend as those conducted in the glasshouse. The ET values started insignificantly during the early growth stage but put on substantial increment progressively to peak first at about maximum tillering and again at heading. Increase in ET values, mainly through transpiration, was attributed to the relative increase in plant size, particularly the leaf area in relation to soil surface area. The transpiration ratio per unit leaf area would almost be constant when leaf area index reached 3.5 and beyond (Sugimoto 1971).

The ET value of MR 84 is relatively higher than other varieties regardless of cropping seasons *(Table 5)*. However, this high ET value from MR 84 was always not significantly different from MR 185. This may possibly be due to the both varieties sharing some common characteristics genetically.

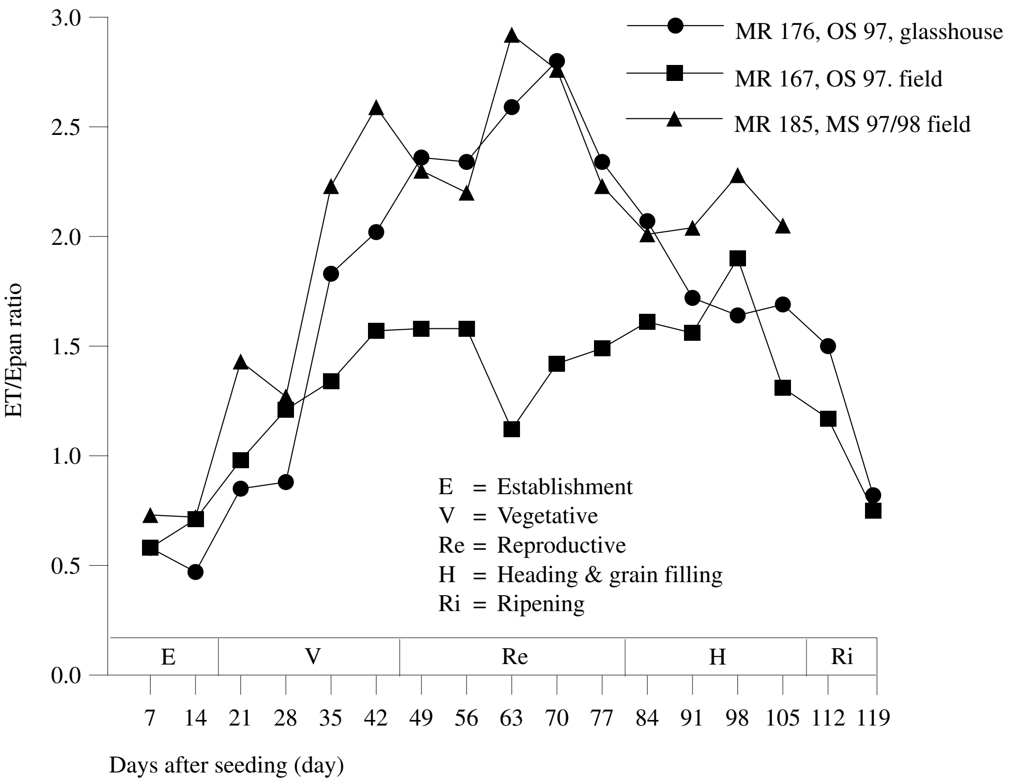


Figure 2. Comparison of ET/Epan ratio under glasshouse and field environment

Table 3. Water requirement of rice varieties MR 84, 159, 185, 211, 219 during off-season 1998

Days after seeding	Duration (day)	Epan (mm)	Rainfall (mm)	ET MR 84	ET MR 159	ET MR 185	ET MR 211	ET MR 219
1–7	7	38.8	45.1	18.3	18.0	17.9	18.0	17.8
8–14	7	33.0	56.6	20.6	21.0	20.8	20.5	21.3
15–21	7	30.5	26.8	29.2	25.8	27.9	28.6	28.9
22–28	7	32.0	29.9	31.3	30.7	25.4	29.8	29.3
29–35	7	35.1	5.2	68.0	65.0	66.4	65.4	63.8
36–42	7	27.8	114.5	66.5	65.1	70.7	70.0	70.0
43–49	7	25.4	61.3	61.7	59.9	69.1	66.4	67.6
50–56	7	30.3	64.5	88.1	88.3	84.2	74.6	86.3
57–63	7	31.2	4.9	115.0	109.2	112.5	120.6	123.3
64–70	7	33.6	169.1	81.9	74.1	80.8	80.2	95.5
71–77	7	21.8	71.1	67.3	60.5	66.7	67.1	79.2
78–84	7	19.9	27.7	72.5	73.4	75.5	75.8	74.7
85–91	7	27.7	5.3	113.7	106.7	114.0	115.2	118.0
92–98	7	23.2	89.7	103.1	84.2	100.8	80.8	108.5
99–105	7	31.9	33.2	102.8	68.4	87.6	68.5	93.7
106–112	7	33.3	59.3	78.0	72.8	72.6	ND	68.5
113–114	2	7.8	5.0	28.2	24.0	27.4	ND	29.2
Seasonal Total	114	483.3	869.2	1146.2	1047.1	1120.3	981.5	1175.6
Seasonal Average/day		4.2	7.6	10.1	9.2	9.8	9.3	10.3

DAS = days after planting on 13 May 98, ND = no data

Table 4. Water requirement of rice varieties MR 84, 185, 208, 209

Days after seeding	Duration (day)	Epan (mm)	Rainfall (mm)	ET MR 84	ET MR 185	ET MR 208	ET MR 209
Main season 1998/99							
1–7	7	32.0	161.3	18.7	18.0	17.5	18.1
8–14	7	16.0	21.4	12.6	15.4	20.4	20.9
15–21	7	27.1	65.3	20.9	26.9	29.1	25.5
22–28	7	30.1	138.3	31.5	34.8	39.1	36.6
29–35	7	34.0	395.6	43.4	40.3	46.0	46.6
36–42	7	28.4	99.5	51.7	57.5	51.1	52.2
43–49	7	26.6	15.0	62.9	58.9	70.6	61.6
50–56	7	21.8	13.3	70.0	56.0	61.5	61.3
57–63	7	22.9	4.8	60.0	57.6	69.0	61.8
64–70	7	21.9	30.6	62.0	91.7	60.5	52.4
71–77	7	27.3	16.9	97.3	107.6	93.6	81.0
78–84	7	32.4	63.1	113.7	102.9	104.8	96.0
85–91	7	35.2	39.5	98.8	108.7	97.5	79.3
92–98	7	35.2	41.0	86.8	63.8	101.3	67.7
99–104	6	25.8	97.5	39.0	38.5	43.6	27.9
Total	104	416.7	1203.1	869.3	878.6	905.6	788.9
Average/day		4.0	11.6	8.4	8.4	8.7	7.6

(cont.)

Table 4. *(cont.)*

Days after seeding	Duration (day)	Epan (mm)	Rainfall (mm)	ET MR 84	ET MR 185	ET MR 208	ET MR 209
Off-season 1999							
1–7	7	28.8	123.4	18.4	18.7	18.0	18.6
8–14	7	34.5	3.8	21.3	21.5	20.7	20.9
15–21	7	33.3	16.1	35.2	32.6	36.8	41.5
22–28	7	28.0	9.7	34.8	26.2	33.5	37.7
29–35	7	25.4	17.6	63.9	53.0	58.7	75.5
36–42	7	30.8	0.0	86.8	69.4	78.5	102.7
43–49	7	25.5	3.8	109.7	96.0	98.9	117.4
50–56	7	24.8	96.0	108.9	96.9	96.8	94.8
57–63	7	32.2	20.0	91.8	87.3	79.5	81.0
64–70	7	31.5	5.6	89.9	94.4	96.2	70.6
71–77	7	25.4	162.8	81.9	88.2	91.0	65.8
78–84	7	31.8	54.7	65.4	75.1	66.3	67.5
85–91	7	27.0	3.6	59.8	65.7	65.6	52.6
92–98	7	35.8	4.1	68.2	72.7	76.7	45.9
99–105	7	33.7	38.0	61.2	59.6	52.8	40.6
106–112	7	27.6	6.2	72.0	66.0	48.8	45.0
113	1	4.3	0.0	12.0	11.1	8.0	7.2
Total	113	480.4	565.4	1081.2	1034.4	1026.8	985.3
Average/day		4.3	5.0	9.6	9.2	9.1	8.7
Main season 1999/2000							
1–7	7	25.5	374.1	18.5	18.3	17.8	18.4
8–14	7	22.9	32.9	23.3	24.0	22.0	21.2
15–21	7	26.9	24.4	37.2	41.0	34.1	32.3
22–28	7	23.8	42.5	34.2	32.6	37.4	34.4
29–35	7	23.9	89.8	39.9	37.5	41.4	43.6
36–42	7	35.0	153.7	48.0	44.0	53.4	56.5
43–49	7	26.7	47.4	29.8	22.2	25.6	23.7
50–56	7	22.3	10.7	48.3	34.7	39.4	39.6
57–63	7	27.5	72.2	63.2	53.5	55.1	60.2
64–70	7	44.8	16.2	100.2	83.1	79.3	99.0
71–77	7	26.3	29.6	55.1	48.8	47.9	57.2
78–84	7	31.8	38.0	68.7	69.0	69.4	73.0
85–91	7	34.2	22.2	81.0	75.6	84.4	90.1
92–98	7	35.5	14.2	87.6	75.2	97.6	101.1
99–105	7	51.6	0.0	70.7	73.5	65.1	49.7
Total	105	458.7	967.9	805.7	733.0	769.9	800.0
Average/day		4.4	9.2	7.7	7.0	7.3	7.6

Effect of seasons on seasonal crop ET

All major granaries in Malaysia practise double cropping. In the northern part of Peninsular Malaysia, the cropping season beginning in September/October is the main season, whereas the off-season begins in March/April. Climatic changes during these two seasons have major influence on crop maturity and seasonal water requirement. In general, sunshine hour and relative humidity are more closely correlated with evaporation, transpiration and hence ET than mean air temperature. Sugimoto (1971) reported that under local conditions, an

Table 5. Analysis of variance of mean daily ET between varieties over four seasons

Variety	Off-season 98	Main season 98/99	Off-season 99	Main season 99/00
MR 84	10.1c	8.4b	9.6b	7.7b
MR 185	9.9bc	8.4b	9.1ab	7.0a
MR 159	9.2a	–	–	–
MR 208	–	8.7b	9.1ab	7.3ab
MR 209	–	7.6a	8.6a	7.6ab
MR 211	9.5ab	–	–	–
MR 219	10.3c	–	–	–
Mean	9.8	8.3	9.1	7.4
CV (%)	2.8	4.1	5.5	5.8

Means followed by a common letter are not significantly different at 5% level by LSD

increase in off-season's crop ET was due to low relative humidity together with a rise in air temperature.

From the seasonal crop ET recorded over the eight seasons under glasshouse (MS 95/96 to OS 99) and averaged over different varieties, the off-seasons' ET at 1 012 mm was consistently higher than the main-seasons' value of 747 mm *(Figure 3)*, and so were the Epan values at 510 mm and 429 mm of the off-season and main season respectively.

Such an increase in off-season's crop ET may be attributed to a longer maturation period of about another 10 days regardless of variety used, and also the influence of weather conditions as seen from the higher Epan values during the growth period.

Comparison of crop ET between direct measurement and estimation methods

Cross comparison of ETs of the rice crop (*Table 6*) derived using the Jensen-Haise method, Hargreaves Radiation method, simulation model Cropwat 7.0, and direct measurement in the open field and in the glasshouse were made. Results for the off-season 1997 for all methods were compared while glasshouse measurement was not considered in the main season 99/00. Seasonal and varietal differences though significant as discussed earlier, were not considered in the comparison of ET between estimation Jensen-Haise method. The Cropwat 7.0 model underestimated ET values by 20% and 30% during the off-season 97 and the main season 99/00, respectively. The Hargreaves Radiation method grossly overestimated the ET values, which may be due to methods.

Results showed that Hargreaves Radiation method registered the highest ET values followed by glasshouse measurement, the direct field measurement and lastly the high mean daily temperature which were quite different from the referred temperate climate. The high glasshouse value obtained was likely to have resulted from the closed environment where the midday temperature has always been higher than 40 °C. The dry surrounding could have further enhanced this condition, where no irrigated crop was cultivated, unlike the field experiment, where the lysimeters were placed in the midst of an irrigated rice field. Similarly, like any other estimation methods and under local climate conditions, ET values for rice crop computed from the Cropwat simulation method should be verified and adjusted accordingly before applying it for water management practices in actual field situation.

Seasonal crop performance

Measured ET in the wet main season has been substantially less than that for the dry off-season *(Table 1)*. While ET was normally more in the off-season *(Figure 3)* and despite usual attempts for such losses to be made good through irrigation supply,

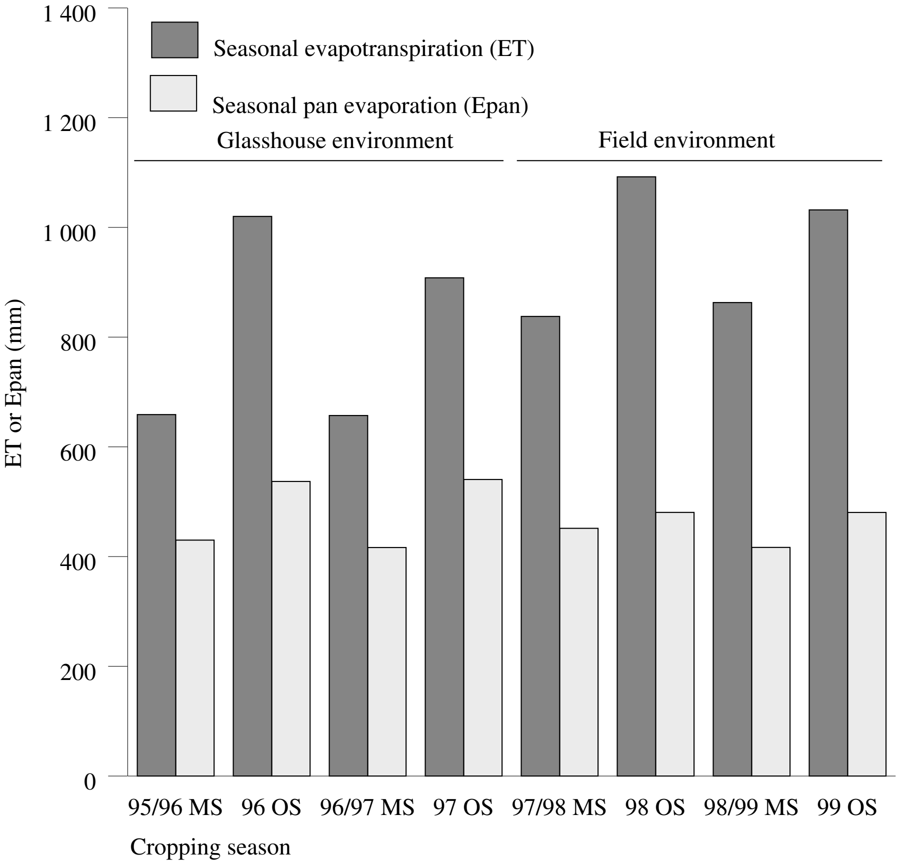


Figure 3. Effect of seasons on seasonal crop evapotranspiration under glasshouse and field environments

crop yield however was invariably less in every of the off-season's average *(Figure 4)* observed during the same period of plant water use studies. A split-split plot analysis of variance was used to account for yearly (a cycle of one main season and one off-season's crop) variation, this being tested to be not significant as the main plot treatment *(Table 7)*. Seasonal effect would accordingly be reviewed as sub-plot while lastly the crop establishment systems be compared as sub-sub plot. Seasonal yield difference was significant for certain years *(Table 7)* with only one particular crop establishment system like continuous direct seeding yielding significantly higher in the main season than off-season *(Table 8)*. When seasonal difference was very significant, yield from every crop establishment system tested performed much better in the main season *(Table 8)*, indicating that it could not have been only one special system being yield enhancing particularly in the main season, nor just any other system being poor yielding in the off-season. Nevertheless, yield of a direct seeded crop may be higher when row-sown instead of being broadcast. Intensifying practices of transplanting also improved transplanted crop yield, marginally though it may have been. From alternating both the establishment methods between the main season and off-season, direct seeding indicated to be productive when practised in the main season as opposed to when transplanting was practised in the same season *(Figure 5)*. Seasonal yield flux was seen to be more that just due to difference in crop establishment systems between the two

Table 6. ET obtained from estimation and measurement methods

Days after seeding (DAS)	Estimation			Measurement	
	Jensen-Haise Method	Hargreaves Radiation Method	Cropwat 7.0 Model	Field Result	Glass House Result
Off-season 97					
01–07	31.7	46.9	34.5	18.9	19.4
08–14	36.0	53.2	34.0	21.4	17.8
15–21	39.6	58.7	33.5	27.4	37.8
22–28	42.2	62.3	33.2	41.7	42.7
29–35	41.2	61.2	33.1	46.0	55.6
36–42	41.2	61.2	33.0	42.9	64.0
43–49	42.9	63.8	32.8	48.6	66.0
50–56	42.7	63.6	33.0	42.0	83.6
57–63	41.9	62.8	33.0	42.6	76.0
64–70	40.9	60.8	33.0	43.2	65.8
71–77	41.2	61.2	33.1	49.2	69.6
78–84	41.0	60.9	32.9	45.0	70.3
85–91	38.7	57.7	32.6	44.1	67.7
92–98	39.4	58.4	31.2	63.9	56.1
99–105	37.6	55.7	29.4	42.3	56.5
106–112	35.5	52.7	27.8	35.3	32.5
112–119	32.2	48.3	25.8	25.2	26.7
Total	665.9	989.4	545.9	679.7	908.1
Main season 99/00					
01–07	29.7	44.7	17.8	18.2	ND
08–14	38.3	55.8	26.1	22.6	ND
15–21	38.1	57.1	34.1	36.1	ND
22–28	40.0	59.9	33.5	34.6	ND
29–35	41.3	62.1	32.8	40.6	ND
36–42	41.9	62.8	33.4	50.5	ND
43–49	42.3	63.9	34.1	25.3	ND
50–56	43.1	64.8	35.1	40.5	ND
57–63	43.6	65.3	35.9	58.0	ND
64–70	40.6	61.2	37.0	90.4	ND
71–77	41.9	62.8	37.8	52.2	ND
78–84	42.1	62.9	38.3	70.0	ND
85–91	40.3	60.2	39.0	82.8	ND
92–98	38.1	57.1	40.0	90.4	ND
99–105	34.2	51.2	37.9	64.7	ND
Total	595.5	891.8	512.8	776.9	ND

ND = no data

cropping seasons. Water budget deficit due to high ET in the off-season which is usually not fully replenished for normal crop requirement may have been amongst several reasons behind such a consistent discrepancy in yield between the two seasons.

Conclusion

From observation made over eight consecutive cropping seasons, evapotranspiration (ET) was quite different between the seasons with it being much higher in the dry off-season. ET was

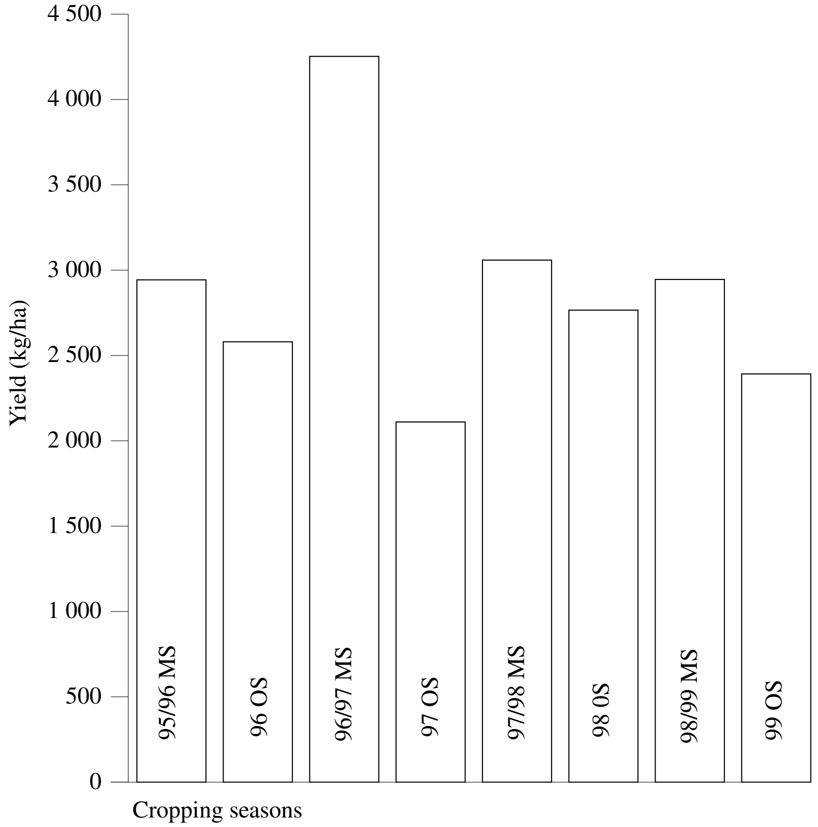


Figure 4. Seasonal crop yield of rice variety, MR 123 from main season 95/96 to off-season 99

Table 7. Analysis of variance for crop yield (kg/ha) seasonal performance of crop establishment system of rice variety, MR 123 from main season 95/96 to off-season 99

SV	DF	F
Replicate (R)	3	3.10 ns
Year (Y)	3	3.50 ns
Error (a)	9	
Season (S)	1	47.5**
Y x S	3	12.99**
Error (b)	12	
Treatment (T)	5	13.45**
Y x T	15	3.05**
S x T	5	2.14 ns
Y x S x T	15	2.14 ns
Error (c)	120	
Total	191	

CV (a) = 28.8%; CV (b) = 29.2%;
CV (c) = 22.5%
** = significant at 1% level; ns = not significant

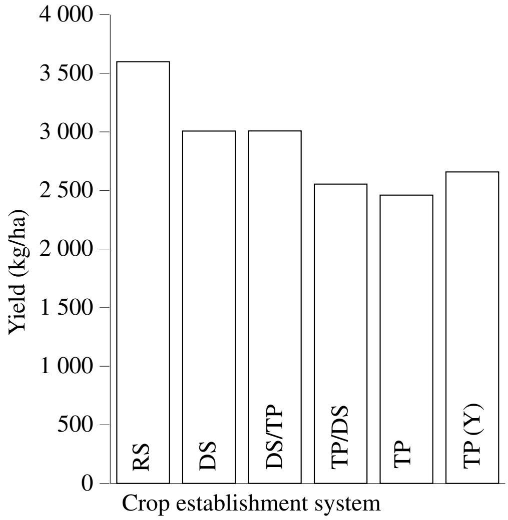
indifferent to seed rate pressure. It may also vary between varieties within a season but to a lesser extent than the quite obvious seasonal difference. All the estimation methods evaluated did not measure up to expectation when compared with actual field readings.

Crop yield in the off-season was generally low, the highest of which could not have exceeded the lowest of the main seasons. Higher yields were obtained from direct seeding, more so when row-sown. Intensifying transplanting practices may also improve transplanted yield marginally. The crop establishment system with the main season's crop being direct seeded was more productive than if it were transplanted.

Table 8. Interacting effects of yearly, seasonal and crop establishment system treatments on crop yield of rice variety, MR 123 from main season 95/99 to off-season 99

Treatment (T)	Crop yield difference (kg/ha) between main season and off-season from			
	main season 95/96 to off-season 96	main season 96/97 to off-season 97	main season 97/98 to off-season 98	main season 98/99 to off-season 99
RS	852 ns	3 291**	–189 ns	720 ns
DS	998*	2 722**	331 ns	1 098*
DS/TP	414 ns	2 076**	239 ns	850 ns
TP/DS	–169 ns	2 045**	619 ns	39 ns
TP	–85 ns	1 509**	699 ns	169 ns
TP(Y)	168 ns	1 212*	63 ns	446 ns

** = significant at 1% level; * = significant at 5% level
ns = not significant
RS = row sown every season
DS = direct seeding (broadcast) every season
DS/TP = broadcast main season, followed by transplant off-season
TP/DS = transplant main season, followed by broadcast off-season
TP = transplant every season
TP(Y) = intensive transplant every season



RS = row sown every season
DS = direct seeding (broadcast) every season
DS/TP = broadcast main season, followed by transplant off-season
TP/DS = transplant main season, followed by broadcast off-season
TP = transplant every season
TP (Y) = intensive transplant every season

Figure 5. Mean seasonal crop yield from different crop establishment systems of rice variety MR 123 from main season 95/96 to off-season 98

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